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PHYSWARE: A Collaborative Workshop on Low-cost Equipment and Appropriate Technologies that Promote Undergraduate Level, Hands-on Physics Education throughout the Developing World

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prepared by

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PHYSWARE
Teaching Kinematics and Action Research

1. Individual Question: What are some of the difficulties you think students have when trying to learn 1D kinematics?

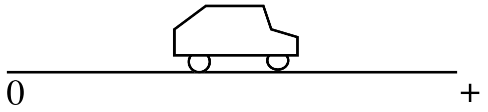
2. Discussion: Share your thoughts about learning difficulties with other participants and write down any new ideas that seem reasonable to you.

3. Pretest: Students using Active Learning materials are often asked to take a pre-test to help instructors learn about what students know before studying a topic. Later an instructor can use the same questions on a post-test to assess how effective his or her teaching is. These tests should not count on the student's grade.

Please complete the 12 multiple choice questions on the sheet entitled "KINEMATICS QUESTIONS FROM THE FORCE AND MOTION CONCEPTUAL EVALUATION." You do not need to show your answers to anyone. You will be given an answer key later so you can check your answers.

KINEMATICS QUESTIONS FROM THE FORCE AND MOTION CONCEPTUAL EVALUATION

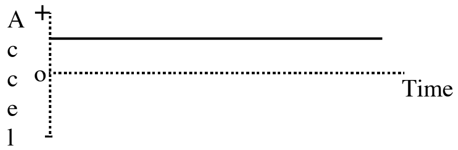
(12 questions from a 47 question examination that includes dynamics questions about forces)

Questions 22-26 refer to a toy car that can move to the right or left on a horizontal surface along a straight line (the + distance axis). The positive direction is to the right.	

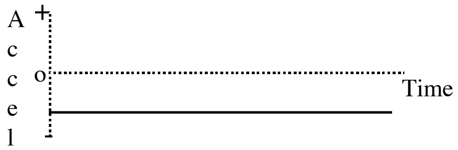
Different motions of the car are described below. Choose the letter (**A** to **G**) of the **acceleration-time** graph that corresponds to the motion of the car described in each statement.

You may use a choice more than once or not at all. If you think that none is correct, answer choice **J**.

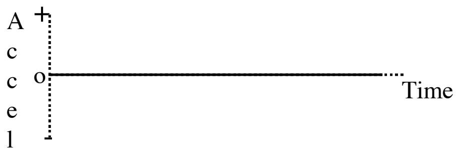
A



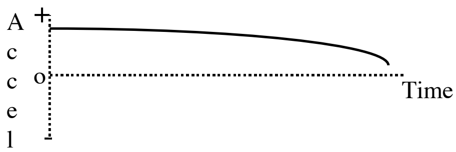
B



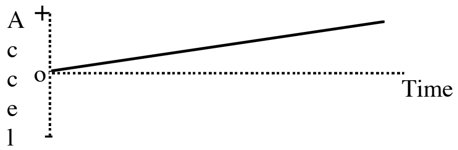
C



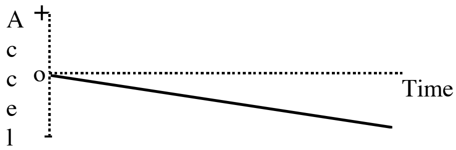
D



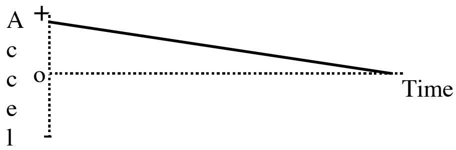
E



F



G



J None of these graphs is correct.

_____22. The car moves toward the right (away from the origin), speeding up at a steady rate.

_____23. The car moves toward the right, slowing down at a steady rate.

_____24. The car moves toward the left (toward the origin) at a constant velocity.

_____25. The car moves toward the left, speeding up at a steady rate.

_____26. The car moves toward the right at a constant velocity.

Questions 27-29 refer to a coin that is tossed straight up into the air. After it is released it moves upward, reaches its highest point and falls back down again. Use one of the following choices (**A** through **G**) to indicate the acceleration of the coin during each of the stages of the coin's motion described below. Take **up** to be the **positive** direction. Answer choice **J** if you think that none is correct.

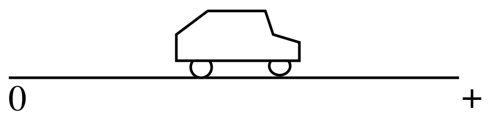
- **A.** The acceleration is in the negative direction and constant.
- **B.** The acceleration is in the negative direction and increasing
- **C.** The acceleration is in the negative direction and decreasing
- **D.** The acceleration is zero.
- **E.** The acceleration is in the positive direction and constant.
- **F.** The acceleration is in the positive direction and increasing
- **G.** The acceleration is in the positive direction and decreasing

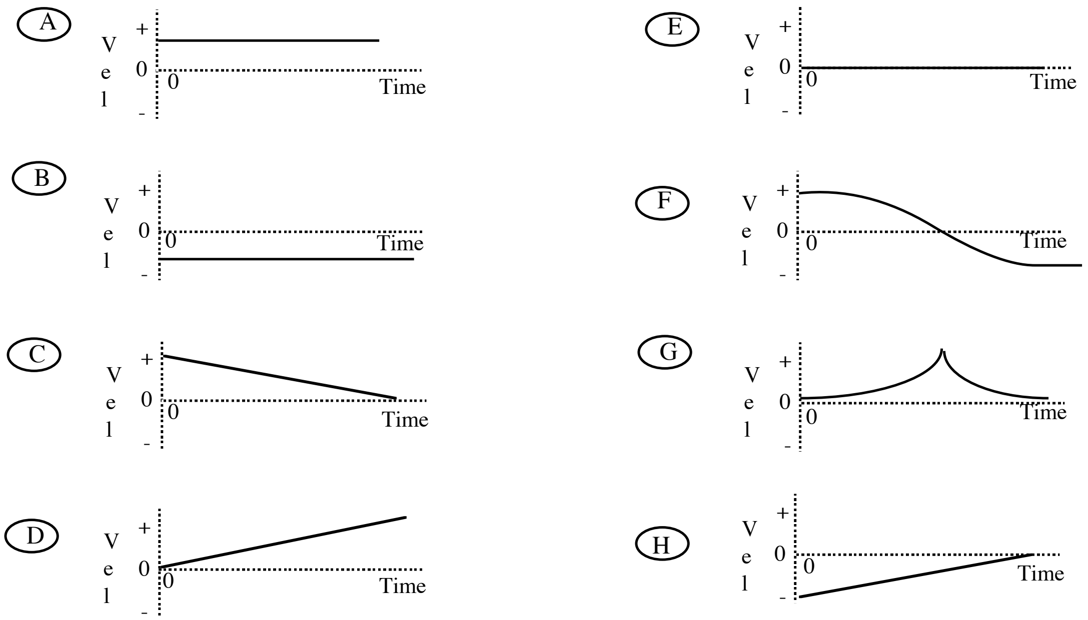
___27. The coin is moving upward after it is released.

___28. The coin is at its highest point.

___29. The coin is moving downward.

Questions 40-43 refer to a toy car that can move to the right or left along a horizontal line (the positive portion of the distance axis). The positive direction is to the right.





(J) None of these graphs is correct.

___40. Which velocity graph shows the car moving toward the right (away from the origin) at a steady (constant) velocity?

___41. Which velocity graph shows the car reversing direction?

___42. Which velocity graph shows the car moving toward the left (toward the origin) at a steady (constant) velocity?

___43. Which velocity graph shows the car increasing its *speed* at a steady (constant) rate?

FMCE
Kinematics Results

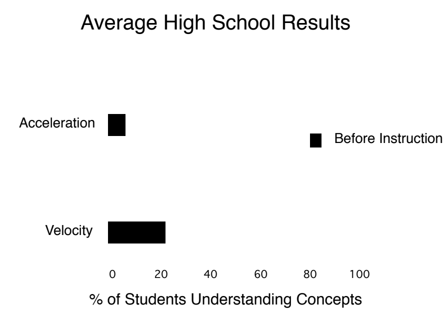
Courtesy of Ronald K. Thornton
Center for the Teaching of Science and Mathematics
Tufts University, USA

Why do we need the use active learning in introductory physics?

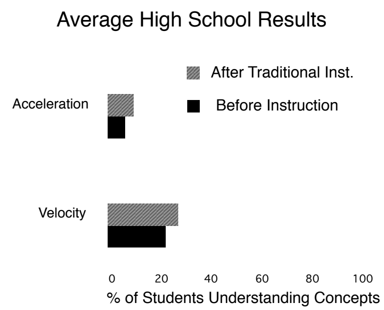
Suspend Disbelief

- Imagine for a moment that we actually know how to measure student conceptual knowledge in physics.
- Let's concentrate on kinematics and Newton's Laws since they are commonly taught in Introductory Physics

US High School--Before Instruction



High School After Traditional Instruction



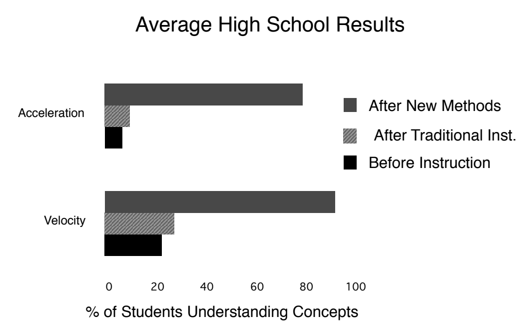
I know what some of you are thinking.

- Another university professor slamming secondary education with no hint of a solution.
- You are only partially right
- I have a hint of a solution
- And if you wait a moment, I'll show you we are all in this together.

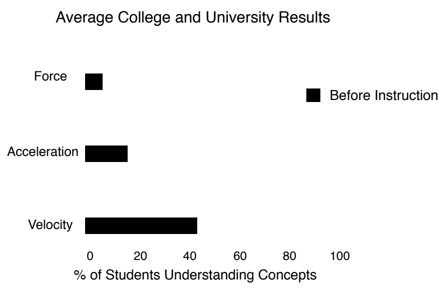
Physics Courses Using New Methods

- We have evidence of substantial, persistent learning of such physical concepts by a large number of students who use active learning methods.
- Such methods also work for students who traditionally had less success in physics and science courses: women and girls, minority students, and those who are badly prepared.

US High School- After New Methods

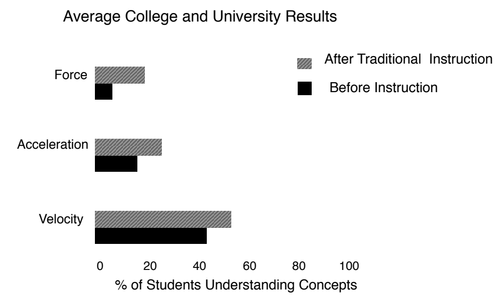


US University Physics Courses Before Instruction



2/9/09 PhysWare_Wk1_MonBlock3 (Action Research and Teaching Kinematics)

US University Physics Courses After Traditional Instruction



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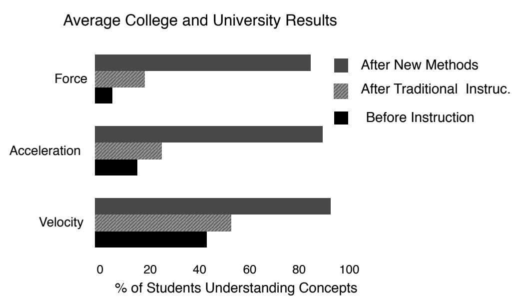
University Physics Courses- After Activity-based Methods



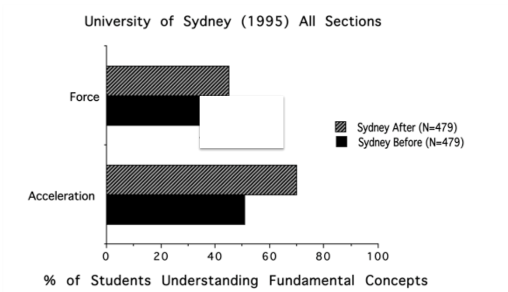
2/9/09 PhysWare_Wk1_MonBlock3 (Action Research and Teaching Kinematics)

But it can't be true everywhere

- What else could you expect from those American universities?

2/9/09 PhysWare_Wk1_MonBlock3 (Action Research and Teaching Kinematics)

University of Sydney Before and After Traditional Instruction



Force is shorthand for Newton's Laws

Note the following

- Sydney students come in on average about three times more conceptually knowledgeable than the "average" US student (Good job!)
- Unfortunately, after good university instruction the gain in conceptual knowledge is similar to traditional instruction in the US.
- The data are from 1995 and given our experience with other schools will be similar today unless significant changes have been made. (Similar result in 1999)
- Ian Johnston did make a significant change in 1999

So what?

- What does it matter if students know these simple concepts?
- Students who don't "understand" often lose interest
- If students don't learn the simple concepts, they don't learn the more advanced ones

Physics & Science Courses Using New Methods

- We have evidence of substantial, persistent learning of such physical concepts by a large number of students who use active learning methods.
- Such methods also work for students who traditionally had less success in physics and science courses: women and girls, minority students, and those who are badly prepared.

Measurement of Time and Distance

On the table are various no-cost or very low-cost materials to be used for measuring time and distance. This set can be increased with materials from your local environments. You might ask your students to contribute to the box by bringing examples of this type of materials

TIME MEASUREMENT BY PENDULA

T1 Take the 3 pendula of different length, tie them to the provided support, and arrange it on a table so that the pendula can oscillate freely

T2 With the wood rule move the 3 pendula from their equilibrium position to the same initial angle and release them from rest. Observe carefully their motion and note the key features you'd to spot-light to your secondary school students

....
....
....
....

T3 Repeat and count how many complete oscillations the two longer pendula make while the shortest one makes 10 oscillations

O long .... O medium ...... O short 10

Briefly comment on problems (if any) encountered
....
....
....
....

T4 Choose which pendulum you want to use as your Pendulum-Clock (P/C) and justify briefly your choice (one complete oscillation being 1 “tick” of this P/C, it will measure time in arbitrary units)

....
....
....
....

T5 Estimate the error in your time measurements when using the (P/C) you have chosen and explain briefly

....
....
....
....

T6 Use the chosen (P/C) to count how many "ticks" it takes for 100 hearth beats of yours (put two fingers on the pulse arteria). Write the number of ticks, the estimated error and the frequency of your pulse

Ticks .... + - ...... Frequency......... + - .... Units ……..

T7 Using simple words explain briefly to your students the advantages and problems of using arbitrary units

....
....
....
....

T8 Use your watch to measure in seconds the value of 1 "tick" of the chosen (P/C) Write the value and its estimated error

Tick (s) .... Error + - ......

T9 Comment briefly on the proposed approach and how it might be useful to your students

....
....
....
....

T10 Any other comment

....
....
....
....

DISTANCE MEASUREMENT with FIBRES, STRINGS AND WOOD RULE

D1 Identify a length in the room that you estimate by eye to be about two meters. Measure it with the wood rule, a fibre and a string (having calibrated them). Measure 3 times with each of these "Distance Meters (D/M)" and write the average value

Fibre .... String .... Rule ....

D2 Estimate the error of your measurement when using the 3 (D/M)

Fibre + - …. …. String + - …….. Rule + - ………

Justify briefly

....
....
....
....

D3 Measuring the length of your PHYSWARE binder with a D/M of your choice

Fibre .... + - …. String .... + - …. Rule .... + - ….

D4 In simple words explain briefly to your students the advantages and problems of using these 3 different "Distance Meters"

....
....
....
....

D5 In simple words explain your students the meaning of Absolute and Relative Error in the above measurements

....
....
....
....

D6 Comment briefly on the proposed approach and how it might be useful to your students and/or similar issues

....
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PHYSWARE at ICTP
February, 16-27, 2009

KIN Teaching Kinematics with Real-Time Lab-work: some examples

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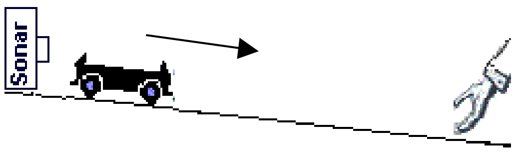

Adapted from
STTIS (Science Teacher Training in an Information Society) EU Project, Jan 1998 – Dec. 2000, Ref: S&S-16-042942,
http://antalya.uab.es/crecim/websttis/general/index.html
SECIF (Spiegare e Capire in Fisica) Italian National Project, Jan 2000-Dec. 01 (in Italian),
http://www.fisica.unina.it/Gener/did/kinfor/secif/index.htm
STTAE (Science Teacher Training across Europe) EU Project, Jan 2003 – Dec 2004
http://www.ellinogermaniki.gr/ep/pathway/index.htm

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KIN: some examples of emblematic paths

1. Introduction

In secondary school teaching still nowadays not enough attention is paid to the common-sense knowledge of the students and to the learning difficulties and cognitive problems arising when it is conflicting with the proposed scientific knowledge. Moreover there is still a diffuse low sensibility in practising teaching strategies which are focused on the students and in realising Open Learner-centred Learning Environments.
Physics is often taught as a theoretical subject and presented essentially as a sequence of rules, formulas and laws. In this perspective the ideal cases treated in many textbooks are obviously chosen as the privileged approach to address the topic to be studied. The physical laws (both general and phenomenological ones) are usually presented as "objects present in nature" to be discovered.
This approach obscures the complex and difficult processes of recognising regularities in the evolution of phenomena, of checking their validity ranges and of modelling them in terms of rules and laws. This attitude, moreover, risks to wide the gap with what the students already know in terms of their own knowledge systems and to feed the wide-spread idea that physics and science are topics suitable only for the most gifted learners. In our experience, to give the students many occasions to express their naive physics ideas and to value the students' common-sense knowledge both as a starting point and an important resource to build upon is a fact of great didactic value.
Knowledge integration is often lacking in current teaching, in spite of its powerful and transversal cognitive value. We mean the integration of various types of knowledge, including: perceptual knowledge; common-sense knowledge, abstract representational knowledge, (e.g. graphs); experimental knowledge (e.g. experiments' settings and optimisations of measures); variational knowledge (e.g. analysis of the consequences of changes in conditions and parameters of an experiment or a simulation); correlative knowledge (e.g. relating different representations of the same phenomenon and comparing experiments and models).
Even if lab-work is often acknowledged as a significant teaching/learning activity, it is given different value and it is performed to very different degrees in current class practice. Roughly the same type of lab-work is proposed across countries and disciplines: small groups of students working with real objects or materials following precise and detailed instructions given directly by the teacher or written on a worksheet; open-ended projects are rarely addressed. We are convinced that valuing much the contributions of lab-work to conceptual and cognitive development is a good teaching investment.

1.1 The Didactic Intentions

The rationale described above is articulated in a set of Didactic Intentions which characterises KIN. Obviously this set is not an exhaustive list, it includes the main features:
- to value the students' common-sense knowledge both as a starting point and an important resource to build upon;
- to emphasise the eliciting and addressing of many common and persistent learning difficulties in Kinematics;
- to exploit, as much as possible a “link to perception approach”, that is to connect one own perceptual knowledge of motion, with e.g. the shape or trend of the graph.
- to focus on real-time experiments using motion sensors, mainly as cognitive tools and not merely as new technologically pieces of equipment; this requires a basic awareness of how the real-time system works, and of its potentialities.

- to follow an approach we refer to as "from real/familiar phenomena to ideal cases/models" ("Real -> Ideal"). This is proposed through emblematic paths that begin with experiments (mainly in real-time) on phenomena that are both well known to the students and familiar in terms of Common-sense Knowledge, proceed through the identification of regularities and rules (via "cleaner" experiments), toward the abstraction of ideal, textbook-like cases/models.
- to familiarise with regularly used educational strategies based on the "Prediction, Experiment, Comparison" learning cycle (PEC), to foster students' expressions of their own ideas and to use different cognitive abilities.
- to implement a mixture of different activities: real-time experiments, lab-work based on everyday materials, paper and pencil work (numerical and graphical exercises); teacher's presentation, etc... No specific relative dosage of these activities is prescribed, it is left to the teacher to adapt it dynamically to the class' needs.

1. 2 Common learning/teaching difficulties in kinematics

Educational research and teaching practice show that in physics the learning difficulties are persistent. These difficulties are often linked to common sense knowledge, that is developed through the common life during the years and is very convenient for the usual life: it is so robust and resistant to changes that often the intuitive knowledge appears to be in contrast with respect to the disciplinary one.
It is important that teachers be aware of such difficulties: in kinematics such difficulties frequently appear as an undifferentiated use of different concepts. It is important to investigate if this is due to mathematical shortcomings or to a confusion between use of common life words in disciplinary context or other. It is important moreover to discuss these difficulties with students and to intervene in correcting them to let student have a lasting learning.
In the following a non exhaustive list of common difficulties is presented: they are grouped in four categories which are obviously not sharp ones, but that may be useful to investigate about their origin.

a) Difficulties related to mathematics

- meaning of the independent variable "time" and of the "functions of the variable time", such as e.g. position, velocity, acceleration;
- meaning of the difference between an instantaneous quantity and a quantity defined as difference between its values at two different times (as e.g. confusion /superposition of the concept of position and displacement);
- meaning of an instantaneous quantity and relationship with its average value (e.g. average and instantaneous velocity);
- meaning of the complete linear relationship ($y = mx + n$) and of direct proportionality ($y = mx$) (as e.g. the role of the initial conditions);
- meaning of a vector, its module and components;
- meaning of the conventions used in a Cartesian reference system

b) Difficulties related to disciplinary contents

- meaning of the initial conditions of a motion (e.g. how to deduce s(t) from v(t), v(t) from a(t));
- confusion between trajectory and position as function of time (e.g. wrong reasoning, as "in a position versus time graph the still object should be represented by a point", is a possible consequence);
- meaning of the dimensional definition of a kinematics quantity (e.g. velocity defined as the ratio distance/time. Reasoning strategies linked to such confusion are "in a going away motion the velocity is increasing as the distance is increasing", "in an approaching motion the velocity is decreasing as the distance is decreasing", "the distance is increasing so the velocity is

positive" or even "a still body has a zero velocity and therefore its distance (position) is always zero");

- meaning of negative velocity and/or acceleration (such quantities are often considered only positive);

c) Iconic Difficulties

- meaning of axis variables of a function graph (e.g. misinterpretations when a v(t) graph is read as if it was a s(t) graph and vice versa; the crossing or overtaking points of two motions represented via two *s(t)* graphs are identified as "they have the same velocity");
- co- relation of the graphs *s(t), v(t), a(t)* of the same motion;
- interpretation of graphs of increasing functions as going up displacements and vice versa for the decreasing functions (the shape of graph attracts);
- meaning of the arrows of the axes (as e.g. in an s(t) graph they are interpreted as indicators of going away motion).
- uniform rectilinear motion: confusion amongst the four "lines" of its kinematics representation (trajectory, s(t), v(t), a(t));

d) Disciplinary versus every day life language difficulties

- meaning of words "velocity", "acceleration";
- meaning of the term "uniform";
- meaning of word "motion" considered as a fourth kinematics quantity (other than position, velocity and acceleration);
- meaning and use of term "deceleration" (that may reinforce the idea that acceleration has to be positive).

The above partial list refers to the one dimension case. In two or three dimensional motions more items can be considered, as e.g. the confusion between radial and tangential acceleration, etc.

2. Examples of implementation of KIN rationale

Hereafter we outline some of the disciplinary aims of KIN and two emblematic paths, which represent a concrete implementation of its rationale.

2.1 Disciplinary aims

The broad disciplinary aims are:

a) to introduce basic contents of one dimension kinematics, as constant velocity motion and constant acceleration motion
b) to address the relation among time graphs of position, velocity and acceleration of the same motion
c) to address the search of simple mathematical functions that fit experimental trends of position, velocity and acceleration versus time, as a first introduction to modelling.

Many specific skills/competencies are expected to be acquired by the students through the approaches suggested by KIN. Some examples are presented in the following non exhaustive list:

- acquire capability in interpreting position versus time graphs or s(t);
- understand the difference between trajectory and position as function of time;
- estimate average velocity values from a *s(t)* graph;
- relate the concept of velocity to the slope of *s(t);*
- understand the difference between instantaneous and average velocity;
- estimate average acceleration values from a v(t) graph;
- relate the concept of acceleration to the slope of *v(t);*
- understand the sign of acceleration in relation with the variation of velocity;
- familiarise with impulsive accelerations;
- understand acceleration due to friction;
- understand how the slope of a ramp is related to the acceleration of a body moving on it;
- be able to interpret a velocity versus position graph.

2.2 Emblematic paths

Hereafter we outline two paths: Path 1 " From students' walks to one-dimension constant velocity motion" and Path 2 " From carts on ramps to one-dimension constant acceleration motion". They reflect the rationale and the didactic intentions of KIN and are intended emblematic not only for the contents they address but also as possible templates, in order to foster to create similar ones. They are not prescriptive, but examples.

2.2. 1 Path 1: " From students' walks to one-dimension constant velocity motion"

For sake of brevity this path will be called P1 from now on. The underlying rationale is mainly inspired to the "Real-Ideal", "Link to perception" and "Addressing learning Difficulties" items of the global rationale (cf. 1.1)

A schematic description of P1 goes through the following steps:

1) to start from experiments about students' walks;
2) to proceed studying the motion of a low-friction cart first on a smooth floor;
3) to proceed further studying how the cart moves on a low-friction track;
4) to extrapolate to the model of an ideal no-friction motion.

This approach is different from a common teaching of kinematics where almost always the ideal case of point-like mass moving on frictionless 1D trajectory with constant velocity is the starting point. This usual procedure requires in fact high capability of abstraction, is demanding for students at the beginning of secondary school and does not facilitate the addressing of common and entrenched learning difficulties.

The rationale of P1 takes much advantage of real - time experiments using an ultrasonic motion sensor.

In Figure 1 are shown typical results of two types of experiments suitable for the steps 1 and 3 of P1.

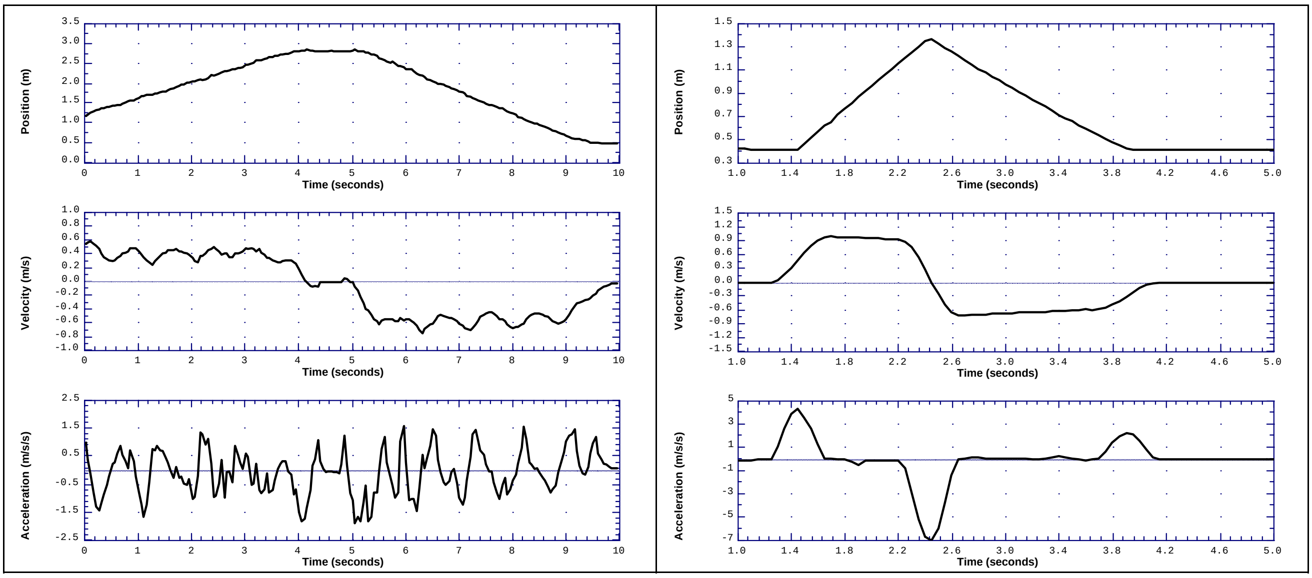


Fig. 1 Real time graphs of a student regular walk (at left) and motion of a cart on a smooth track (at right)

At left are shown the graphs s(t), v(t) and a(t) of a regular walk of a student moving away from the motion detector, stopping for a little and then moving toward the detector. The graphs clearly indicate the substantial linearity of the s(t), the modulations of the steps in the quasi constant velocity, the fluctuations of acceleration around a zero value.

The second step (not shown in the figure) is to study the motion of a cart on smooth floor, the initially still cart, having been given a quick kick, moves away from the motion sensor, then hits a wall and comes back. The linearity of the s(t) graph is now a little better than before; the trend of velocity is substantially constant, apart the slow decrease when friction's effect are more remarkable; and the acceleration graph shows well both the quasi zero trend and the impulsive peaks of the initial kick, the hit and the grasping to stop the cart.

The third step of the path (shown in Figure 1 at right) is to get the cart move on an horizontal smooth track, of the type usually used in school experiments; the experimental results are similar to those obtained in step 2, but the effects of friction become less evident. The s(t) trend can be well represented by a linear fit and the quasi constant value of velocity is easily calculated both from s(t) and v(t).

Through the path P1 the students can be guided to perceive the case of one dimension motion of a point-like object on a friction-less track and its mathematical model as a very useful abstraction describing an ideal case, which is reached at the end of a process implying several steps through a refining procedure rather common in the history of physics.

The introduction to simple modelling is done through a two-step type approach: a) recognise firstly relations of order and common trends in the observation of experiments about students' walking (e.g. quicker walk-steeper s(t); brisker pace- more step modulation in v(t); fast motion inversion-steeper change in sign in v(t); b) search for simple mathematical functions which best describe the collected data; this can be done, according to the needs of the class, through the fitting tools of the used real-time system or/and exporting the data in the spreadsheet.

2.2.2 Path 2 " From carts on ramps to one-dimension constant acceleration motion"

Once again, this path will be called P2 from now on. The main goal is to build awareness of the model describing a constant acceleration motion. The starting point is the students' naive knowledge about motions of carts on ramps and about falling objects and the observation of the related phenomenology.

A schematic outline of P2 is like this:

1) to start studying a motion of a low friction cart on a ramp, e.g. how it descends toward the ramp bottom;

2) to proceed through a variational approach, e.g. what happens if the angle changes, if the motion sensor is at the top/bottom of the ramp, if the initial velocity is zero/not zero, and so on;

3) to proceed further studying the motion of a ball bouncing on the floor;

4) to model the s(t) of the cart and of the ball with a quadratic function;

5) to co-relate the quasi quadratic s(t) with the quasi linear trend of v(t) and the quasi constant a(t);

6) to abstract the ideal no-friction, constant acceleration motion of a point-like mass moving on a one-dimension trajectory;

7) to proceed further studying multiple up and down of the cart on the ramp and multiple bouncing of the ball to get a feeling of the damping process and of friction effects.

Very often the constant acceleration motion is presented by textbooks and teachers starting from the ideal case of a free fall. The approach implemented in P2 is once again based on proceeding from real/familiar cases to ideal models and on exploiting the common-sense knowledge about toy car moving on inclines and about the fall of balls and balloons.

As P1, also this path takes much advantage of real - time experiments. In Figure 2 typical results of experiments appropriate for step 2 are shown.

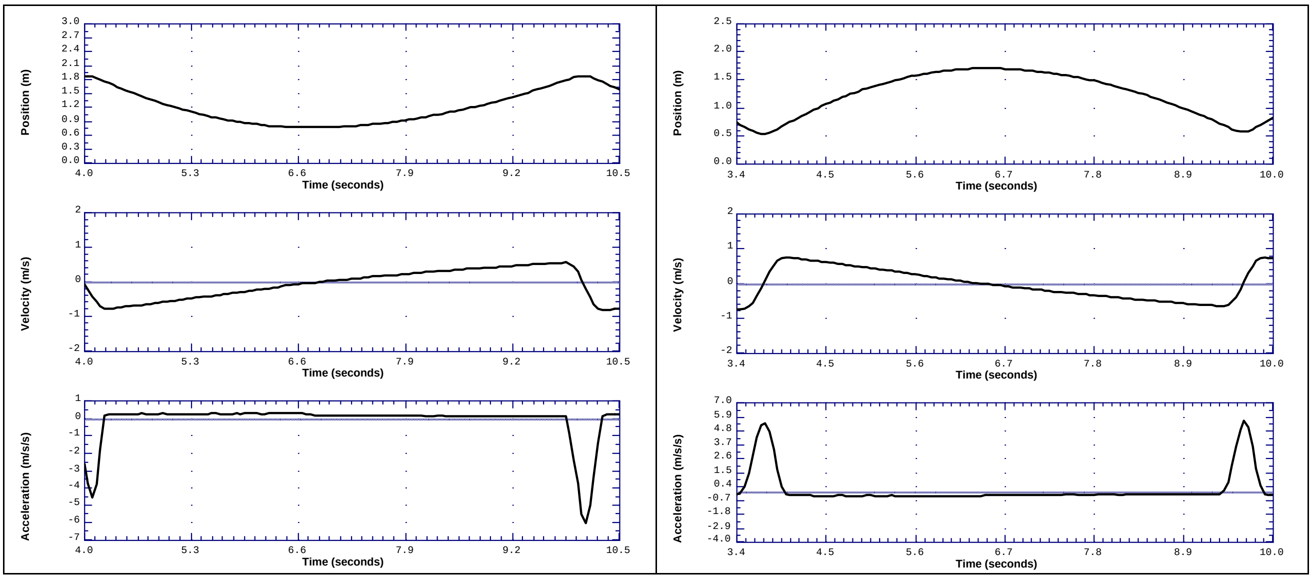


Fig. 2 Motion of a cart on a ramp: at left the motion sensor is at the top of the ramp; at right the sensor is at the bottom.

At left are shown the graphs s(t), v(t), a(t) of the motion of a low-friction cart on a ramp. The motion sensor is at the top of the ramp and the cart, still at the bottom, is given a fast kick. It moves up toward the sensor, inverts its motion when the maximum height has been reached and then moves back to the bottom of the ramp. The non linear shape of s(t) is evident, together with a linear trend of v(t) and a quasi constant value of a(t). At right are shown the same graphs in the case of a very similar motion measured with a sensor located at the bottom of the ramp. The effects of the change in the origin of the co-ordinate system are clear and it is easy to address learning difficulties

related to system of reference, conventions and similar issues. The similarities and differences of these two types of motion can be easily studied by varying the slope of the ramp.
A fit with a quadratic function of time describes reasonably well the trends of s(t) of both motions, even if it is clear that they are not mathematical parabolas because of the friction effect.
Step 5 is to abstract to the quadratic function model for s(t) of a constant acceleration motion. Once again this modelling start from recognising a non linear trend in the observed s(t) graphs, a quasi linear trend of v(t) graphs, proceed to identify rules to describe these regularities as, for instance, higher initial velocity – higher maximum reached height on the ramp; "valleys" in the s(t) shape – sensor at the top of ramp and so on; later the modelling proceeds searching for the simplest mathematical function which describes best the experimental trends.
Figure 3 shows typical results of experiments appropriate for step 7. At right, s(t),v(t), a(t) graphs of a cart moving up and down a ramp, the sensor is at the ramp top and multiple kicks are given to the cart when it reaches the ramp bottom). At left are shown s(t), v(t) and a(t) graphs of multiple bouncing of an elastic ball falling on floor.

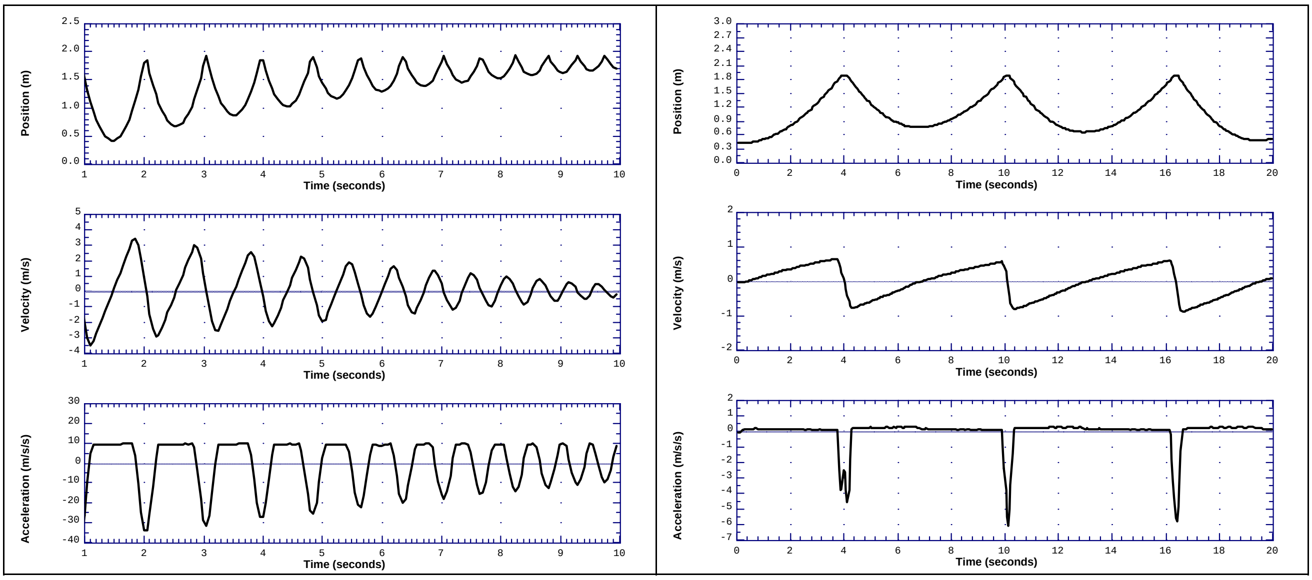


Fig. 3 At right, multiple up/down of a cart on a ramp, at left multiple bouncing of an elastic ball on the floor .

It is evident the difference between the regular decrease of the amplitude of the quasi parabolas describing the multiple bouncing of the ball and the pattern of those of the cart, due to the difference in the fast kicks given to the cart. This difference reflects also in the v(t) and a(t) trends.
The multiplicity of quasi-parabolic sections of s(t) allows to introduce the effects of friction and to establish relations between the kinematics and dynamic description of motion.

2.3 Example of a script of an activity

The implementation, in class work, of paths like the ones proposed above is not unique, it can be done in various ways. The main suggestion is the resonance with the didactic intentions of the path. The specific ways to implement it depend on the school context, the class needs and the teacher's goals and interests.
Here we propose, in the format of a brief script, an example of a class activity addressing the effect of friction on the motion of a cart on a ramp. This content may be amongst the ones addressed through P2. The aim is to propose a technique to plan an activity and to design the structure of students' worksheets. The format of a short "script" has been chosen to point out that many specific ways of implementing the proposed activity are possible and that step-by-step instruction is not coherent with the KIN rationale.

The "script" is aimed at the teacher, and the phrasing suggests actions to be done by him/her. The focus is on Real-Time experiments and analysis of their graphs, to facilitate the take-up of these approaches. Therefore in the script several teacher's actions are not explicitly indicated, as for instance those regarding experiments other than Real-Time ones and links with textbooks.

Cart on ramp. Effects of friction

- Types of activities: real-time experiments and paper/pencil work on printouts of experimental graphs
- Prerequisites: the students are already familiar with the use of an ultrasonic motion detector; graphs of acceleration versus time, a(t); definition of average acceleration; acceleration as slope of v(t).
- Recommendations: facilitate the turn-over of all students in doing the experiments; running the real-time apparatus; deciding the appropriate graph display and the data collection time interval. Insist on having them practice the PEC cycle.
- Reference: Catalogue of Real-Time Experiments, Experiment #5 and #6.

a) Help the students prepare an experimental set-up with the sensor on-top of the ramp and check that the motion is well "seen" by the sensor. Suggest trials to avoid artefacts and get a feeling of the fast kick needed to have the cart move up the ramp.
b) Propose the students, with the sensor off, to launch the cart a few times and observe how it moves up and down the ramp. Ask them to predict and sketch s(t), v(t) and a(t) graphs. Note and share the key ideas/words used. Elicit their ideas about the role of friction in the observed motion.
c) With the sensor on, the experiment is repeated; the files are saved with evocative names. Guide the students to choose an experiment to analyse in detail; optimise the display of its data and compare them with their predictions; if needed, suggest repetition of the PEC cycle
d) Focus on analysis of acceleration, comparing the motion of the cart when it goes up and down; ask the students' opinion. Note and share their ideas, paying attention especially to what they think about differences in the up-down acceleration and the sign of acceleration (e.g. negative acceleration when going up, positive when coming down)
e) Analysing a v(t) graph with an appropriate zoom, call the students' attention on the variation of slope between the linear sections of the graph describing the up and down motion of the cart. If needed, have them repeat the experiment to understand that, with the chosen set-up (sensor on top of the ramp), the going up velocity is negative (toward the sensor) while the going down velocity is positive (away from the sensor). To clarify how the sign depends on the co-ordinate system used, it may help to repeat the experiment with the sensor at the bottom of the ramp, paying attention to avoid artefacts due to the hand kicking the cart
f) Suggest that friction opposes the motion, asking to exemplify evoking every-day experiences where this happens and guide the students to converge toward the idea that it makes sense to assume, as a first simple model, that friction force is opposite to the motion velocity
g) in this framework ask to estimate, from readings of v(t) slopes, values of average acceleration of the up and down motion. Guide to "see" the difference and ask to explain it
h) Suggest to analyse the co-relation between v(t) and a(t) graphs; have the students optimise the image of the two graphs, using the same time intervals and appropriate zoom. Call the attention on the correspondence between the change of slope in the linear sections of v(t) and the change of values in the constant sections of a(t)
i) Ask to repeat the experiment having increased friction in various ways (for instance taping, under the cart, a piece of cloth which slides on the track) and to observe the difference with the previous measures

j) Help the students to summarise this activity; focus on two conclusion: - in the assumption of no friction, the cart acceleration is the same when it moves up and down and represents a fraction of the gravity acceleration depending of the ramp angle; - friction is responsible of the difference between the acceleration values and that acceleration due to friction force is opposite to velocity
Such a "script" may be used to design students' worksheets and to plan guidelines for the class activities.

3. Guidelines for teachers

In this section we give some indications for implementing the paths of Section 2, for performing the class activities and for the use of the students' worksheets.

3.1 Some general suggestions

Prerequisites: KIN is aimed at 14 – 16 years old students, but can be easily adapted to different age range. The students should already be familiar with:

- co-ordinate systems
- functional relations between two variables
- reading and interpreting Cartesian graphs
- basic kinematics elements as position, displacement, time interval, distance, etc…

1. the basic of Real - Time experiments.

Real – Time experiments' apparatus. It can be any of the commercially available ones (as Vernier, Pasco, etc…). The one usually used by the authors of KIN is MBL[1]. An optimal setting is to have several apparatuses so that the students can work in small groups (3-4 students). In our experience, it is appropriate to work also with only one Real - Time system, if a good turn over of the students working together with teacher is assured. The low friction carts and tracks are those usually present in the ordinary resources of school laboratory equipment.
Time Schedule. A plausible time schedule for each of the two emblematic paths described in the following is about 4-5 class periods.

3.2 Types of class activities

The two emblematic path P1 and P2 presented in Section 2 can be implemented in class through different types of class activities. Here the focus is on the real-time experiments on which many class activities can be based; several other activities are suggested by the paths, as paper and pencil tasks, lab-work with every-day materials, etc.
No instructions are given about details of the activities, the teacher will choose the specific tasks to be proposed to the students in resonance with the rationale of the path and the specific needs of the class, including remedial activities about contents which are supposed to be known. The real time experiments referred to are included in a "Catalogue of Real-Time experiments" presented in the following. The list of the experiments is:

2. Student walk: going away, stop, coming back
3. Students' walking with crossing
4. Student on an office chair
5. Cart moving on smooth track

[1] MBL (Microcomputer Based Laboratory), has been developed by the Centre for Science and Math Teaching, Tufts University, Medford MA 02144, USA (R. K. Thornton Director)

6. Cart moving up and down on a ramp (motion detector on top)
7. Cart moving up and down on a ramp (motion detector on bottom)
8. Bouncing of a ball on a smooth floor
9. Oscillations of a pendulum

For P1 you can refer to experiments 1, 2 and 4, for P2 you can refer to 5, 6, and 7.

4. Use of students' worksheets

An example of students' worksheets broadly related to Path 1 is reported hereafter.
Each worksheet addresses a particular disciplinary learning difficulties (e.g. confusion between s(t) and trajectory, meaning of the negative velocity, etc.), but, in the meanwhile, the other common learning difficulties outlined in 1.2 are touched. The set has been built according to the Real →Ideal rationale (cf. Didactic Intentions in 1.1), but it is left to the teacher to pint out this aspect to the students. A possibility is, for example, to give, at the end of the activities, a critical summary which focuses on the main elements of the conceptual chaining of the entire worksheets' set.
The tasks proposed aim at helping the students to acquire observation, prediction and comparison capabilities, through first simple implementation of a PEC cycle; moreover the perceptual and common sense knowledge is also exploited, especially in those experiments which study students' walks. An introduction to a first simple modelling is also proposed (cf. worksheet #7).
This group of worksheets does not pretend to be an exhaustive example of implementation of all the aims of Path 1. As matter of fact, no questions are proposed on several issues, as: artefacts which might appear in the R-T graphs, signals describing transients or rapid phenomena (start of a motion, stop, inversion, and so on), detailed analysis of some disciplinary node (the relation between average and instantaneous velocity, the role of the friction in causing a not constant velocity, etc.). The teachers will choose their own approach and will decide to design their own worksheets according to their class contexts or to use this set as it is.
As far as the experimental set-up is concerned, the worksheets #1 to #8 refer to RT experiments on students regular walks (see Exp.1 of the Catalogue of Experiments), whereas the 9 and 10 refer also to RT measures of motion of a cart on a horizontal track (see Exp.3 of the Catalogue of Experiments). Measurements of distances with tape-meter and estimations of time intervals are also suggested together with paper and pencil tasks.
In the following a summary of specific aims and tasks is presented for the case of Worksheets #1 and #10, as possible hints for teachers in designing their worksheets. Some of the aims are tagged by an *, to indicate that they are not fully developed in the worksheet' tasks or that no specific related tasks are present, but that they could be included there in a coherent way.

SW#1: Stillness

Specific aims	Tasks given to students
- Recognition of axis variables, units and scales on axes - Prediction of s(t) and v(t) graphs (of a still student) and comparison with the measured ones - Reasoning about graphical representation of s(t) and v(t) - Analysis of the description in words of disciplinary definitions and experimental graphs - Addressing the confusion between trajectory and s(t)*	1) Measure the initial and final position 2) Use appropriate scales and units on axes 3) Draw the predicted s(t) and v(t) 4) Draw the experimental results 5) Compare (3) and (4) and comment 6) Describe in words the experimental results 7) Activity's summary and student's questions

SW#10: Cart motion versus student's regular walk : acceleration

Specific aims	Tasks given to students
- Accelerations in a regular walk in relation with that of	1) RT measure of v(t) and a(t) of cart motion on a

a quasi constant velocity cart motion - Address the meaning of arithmetic mean of acceleration values and its link to average acceleration* - Analysis of the description in words of disciplinary definitions and experimental graphs - Reasoning about transients phenomena*	horizontal track and draw the experimental results 2) Describe in words of experimental results and reasoned comments 3) RT measure of measure of v(t) and a(t) of a regular student walk and draw the experimental results 4) Compare between the two a(t) and comments 5) Identify of constant accelerations 6) Activity's summary and questions

The worksheets list is:
SW1: Stillness
SW2: Regular walk: average velocity estimate from s(t) graph
SW3: Trajectory versus s(t)
SW4: Regular walk: average velocity as function of time interval
SW5: Regular walk: first fit of average velocity
SW6: Negative velocities
SW7: A first summary on regular walks
SW8: A first modelling of regular walk
SW9: Cart motion versus students motion: s(t) and v(t)
SW10: Cart motion versus students motion: v(t) and a(t)

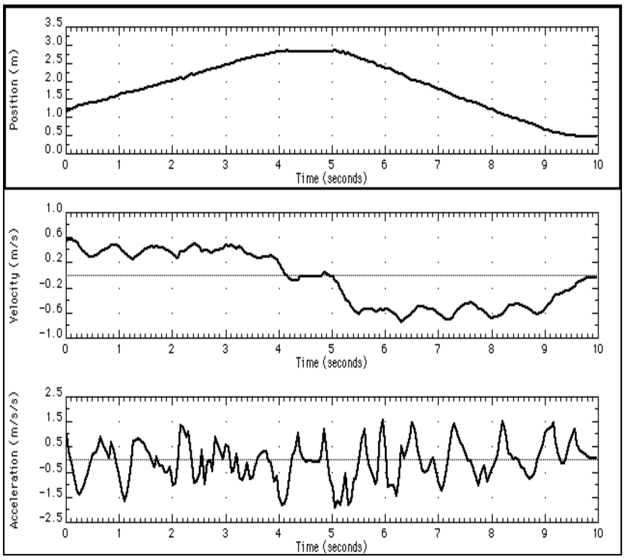
Catalogue of Real-Time experiments

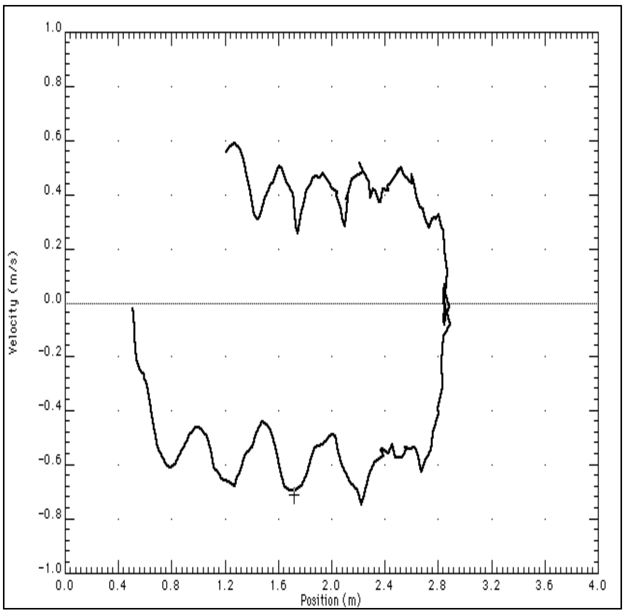
1. Student walk: going away, stop, coming back
2. Students' walking with crossing
3. Student on an office chair
4. Cart moving on smooth track
5. Cart moving up and down on a ramp (motion detector on top)
6. Cart moving up and down on a ramp (motion detector on bottom)
7. Bouncing of a ball on a smooth floor
8. Oscillations of a pendulum

In the description of the experiments the numerical values are written with one or two decimal digits, for sake of clarity, the accuracy of the RT measurements here described has to be estimated each time the experiment is performed.

1. Student walk: going away, stop, coming back

What do you need? A sonar.
How to perform the experiment? The sonar, on a table, in such a way it can "see" the person who is walking away regularly, stops, and comes back. The sensor measures the position of the first object from which the ultrasounds are reflected, so attention must be paid to fluttering dresses, as they can disturb the measure.





Typical trends

s(t): the first part is a going away motion (positive slope). During the time interval in which the person stops, (about 1.30 s), s(t) is constant. During the subsequent motion (coming back), the trend of s(t) is linearly decreasing (negative slope of the curve). Globally the graph is quite regular, the part corresponding to the going away motion presents a smaller slope as compared with the coming back section.
v(t): the irregularities of the "steps" modulating the constant value of velocity, appear clearly. During the going away motion v(t) is positive and its average value is about 0.43 m/s, then the velocity becomes zero when the person stops. During the coming back motion v(t) is negative and its value is about 0.55 m/s.
a(t): the acceleration is substantially zero, even if there are strong irregularities due to the steps.
v(s): the curve in the phase space (v,s) is open because the person did not come back to the position where he/she started. The graph is built up clockwise, given the usual convention of the co-ordinate system (the distances increase going away from the origin). The fluctuations due to the steps appear clearly and it is also clear that the velocity during the going away motion is smaller than in the subsequent motion.

Notes.

The experiments of walking in front of a sonar allow to connect the perceptual knowledge of the motion ("I can feel that I am going slower or faster, that I stop, that I approach or away…") to the graphical representation of the motion through graphs of the kinematics quantities. With these experiments one can address various learning difficulties: a) the confusion between trajectory and changes of the position with time; b) the kinematics representation of the inversion of the motion direction; c) the relationship among average velocity and the slope of a linear s(t); d) the change in sign for v(t); e) the physical impossibility to realise trends with a very steep change, because it would imply a infinite value for the acceleration.

Moreover this kind of experiments allows to acquire familiarity with the multirepresentation of the same phenomenon.

Paper and pencil works: It is useful to involve the students in activities of graphical analysis on printouts of results of the experiments they have done or on the above graphs. Examples (not in order of priority):

- estimate the average velocity from the s(t) graph for the going away (or coming back) motion and compare this value with the corresponding values indicated by the v(t) graph;
- compare the moving away and the coming back motion through the analysis of the v(s) graph;
- fix one time value and describe what is observed for the three graph s(t), v(t) and a(t) at that time;
- write the s(t) equation for the moving away and the coming back motion starting from two couples of data taken by the experimental s(t).
- repeat the experiment walking first toward the origin and then going back and compare the resulting graphs with these;
- estimate of the shaded area below the v(t) curve and describe its meaning
- extract from the v(s) graph the initial condition for the motion
- propose different ways to perform the same experiment, but trying to eliminate the fluctuations due to the steps (for example shuffling the feet).

2. Students' walking with crossing

What do you need? A sonar.
How to perform the experiment? The sonar is placed on a table, so that it can "see" the person walking. The experiment is performed firstly with the real-time system off: two persons walk regularly one toward the other and their position and the time of the crossing are observed. Then the experiment is repeated in two phases with the real-time system on: in the first phase a student walks, in the second phase another student walks in the opposite direction, so to perform a deferred crossing. The sensor measures the position of the first object from which the ultrasounds are reflected, so attention must be paid to fluttering dresses, as they can disturb the measure.

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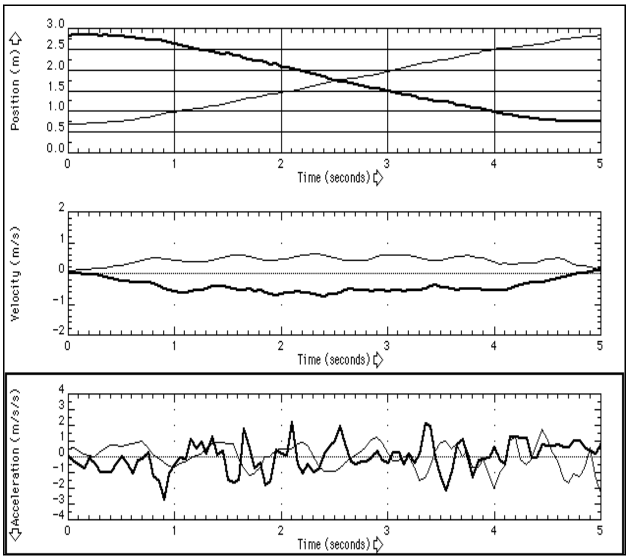
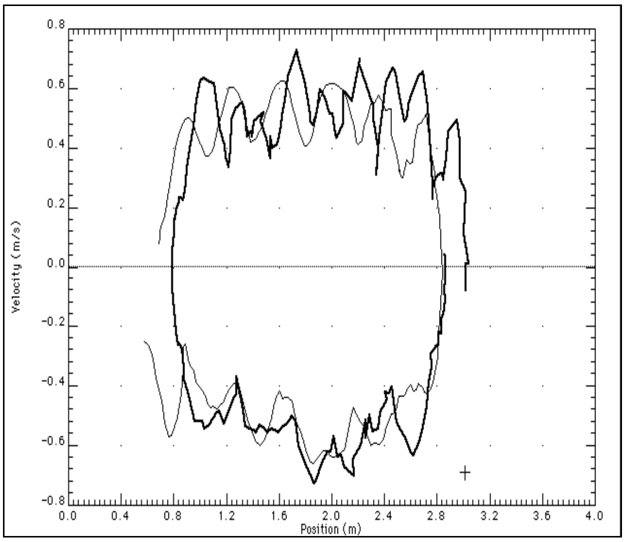




Typical trends

s(t): Both motions are quite regular. Both persons are still for about 0.50 s, the person that is going toward the sonar has a s(t) with positive slope, whereas the s(t) of the approaching walker has a negative slope. Both walked with almost the same average velocity . The position and the time relative to the crossing are found by looking at the intersection of $s_1(t)$ with $s_2(t)$.

v(t): both $v_1(t)$ and $v_2(t)$ show an almost constant value, except for the steps modulations and the clearly visible transients, which represent the change from still position to walking and from walking to the stop. The velocity of the going away motion is positive whereas that of the approach is negative; their average value are 0.40 m/s and –0.40 m/s, respectively.

a(t): the two a(t) are substantially zero, and both curves are very irregular. The irregularities are due to the steps and to the double application of the finite differences to find them from the s(t) data.

v(s): the two curves are very similar and quite symmetrical around the position axis, given the almost equal absolute value of the velocities. Both the curves are clockwise: it is useful to clarify this point, as the wrong idea that they are build up one clockwise, the other anticlockwise, is very common.

Notes.

The experiments of walking in front of a sonar allow to connect the perceptual knowledge of the motion ("I can feel that I am going slower or faster, that I stop, that I approach or away…") to the graphical representation of the motion through graphs of the kinematics quantities. With these experiments one can address various learning difficulties: a) the confusion between trajectory and changes of the position with time; b) the kinematics representation of the inversion of the motion

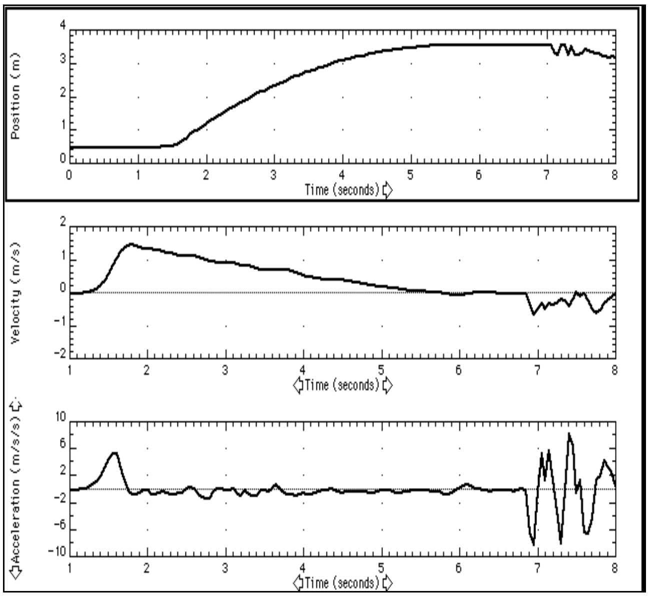
direction; c) the relationship among average velocity and the slope of a linear s(t); d) the change in sign for v(t); e) the physical impossibility to realise trends with a very steep change, because it would imply a infinite value for the acceleration.
Moreover this kind of experiments allows to acquire familiarity with the multirepresentation of the same phenomenon.

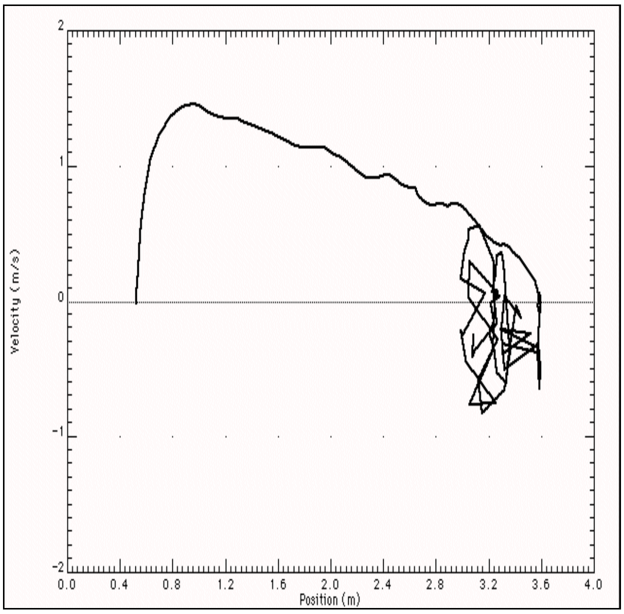
Paper and pencil works: It is useful to involve the students in activities of graphical analysis on printouts of results of the experiments they have done or on the above graphs. Examples (not in order of priority):

- estimate the average velocity from the s(t) graph for the going away (or coming back) motion and compare this value with the corresponding values indicated by the v(t) graph;
- compare the moving away and the coming back motion through the analysis of the v(s) graph;
- fix one time value and describe what is observed for the three graph s(t), v(t) and a(t) at that time;
- write the s(t) equation for the moving away and the coming back motion starting from two couples of data taken by the experimental s(t).
- repeat the experiment walking first toward the origin and then going back and compare the resulting graphs with these;
- estimate of the shaded area below the v(t) curve and describe its meaning
- extract from the v(s) graph the initial condition for the motion
- propose different ways to perform the same experiment, but trying to eliminate the fluctuations due to the steps (for example shuffling the feet).

3. Student on a office chair

What do you need? A sonar, a office-chair with wheels, a quite smooth floor, a wall or obstacle to stop the motion after a while.
How to perform the experiment? The sonar is on a table so that it can "see" a student sitting on the chair; a very fast push (for example, pushing with legs against the table) is given to chair to start its going away motion Attention must be paid to give a push that maintains the chair in a trajectory inside the sonar measurement cone.





Typical trends

s(t): the initial part of the curve shows clearly the time interval (about 1.70 s) in which the chair is still, then the s(t) graph shows a parabolic increase, typical of an accelerated motion, with a downward concavity, because of the friction acting between wheels and floor; it becomes almost flat near the end. The irregularities in the final part (7 - 8 s) are due to the collision of the chair against a wall (obstacle): the chair does not stop the motion immediately and goes back slightly.
v(t): the velocity of the chair is, at the beginning, zero, then there is a fast change due to the push: the quite steep variation corresponds to the initial positive peak in the acceleration versus time graph. After that, the v(t) decreases almost linearly because of friction and goes to an almost constant and very small value. The collision against the wall stops the chair, and in the interval 7 - 8 s in which the velocity becomes negative, the slight coming back of the chair appears clearly.
a(t): the initial peak, due to the fast push, is clearly seen: its duration is about two tenth of second. After the peak, the acceleration is negative, substantially constant, and its value is about -0.2 m/s^2. The collision against the wall and the slight coming back appear on the graph as strong fluctuations around zero.
v(s): the curve is quite regular, exception made for the final part that well describes the collision and the moving back of the chair. The fast initial increase of velocity in the first few centimetres of the motion (due to the fast push) appears clearly. The going away phase is characterised by a decreasing velocity.

Notes.

With this experiment it is possible to clarify:
a) the difference among impulsive forces and constant forces: this allows to address also those learning difficulties connected to the idea that the push force remains in the body also when the action of pushing has ended.
b) the parabolic shape of the s(t) graph , that characterises an accelerated motion,
c) how the friction, however small, can determine a decrease of the velocity.
In order to better characterise friction, it is useful to repeat several times the experiment, on more rough or more smooth floors and with chairs with different types of wheels.
Moreover this experiment facilitates an understanding of aspects of the transition kinematics-dynamics. In this kind of motion, where there is a fast initial change of the velocity, the use of the motion sensor allows a good visualisation of the initial phase of the phenomenon, because of the many gathered data (usually various tens of measurements for second). The correlation between impulsive force and initial acceleration can be addressed also through the relationship between the intuitive reasoning linked to the perception of the push and the representation of the initial peak in a(t). On this respect it is useful to repeat the experiment changing the intensity of the initial push and the kind of chair.

Paper and pencil works: It is useful to involve students in activities of graphical analysis, on printouts of results of the experiments they have done or on the above graphs. Examples (not in sequential order):

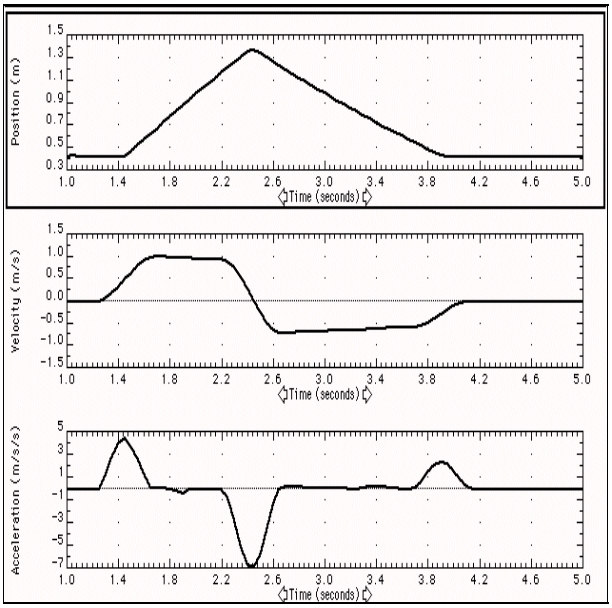
- Evaluate from the a(t), v(t), s(t) graphs the duration of these phases of the motion: initial push, accelerated motion, collision against the wall;
- Estimate from the a(t) and v(t) the push duration values and compare them;
- Evaluate from the v(t) graphs the value of the acceleration during the motion and compare it with the value derived from the a(t) graph.

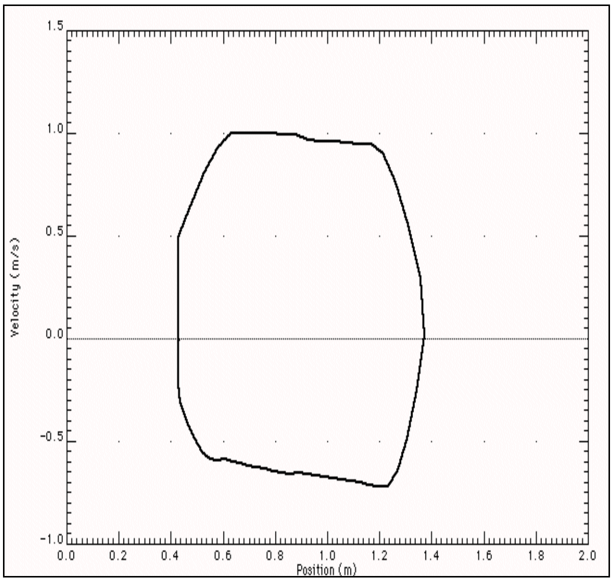
Use also to: clarify the difference between the transient needed to create the initial velocity and the subsequent motion; the difference between impulsive and constant forces.

4. Cart moving on smooth track

What do you need? A motion detector, a smooth track

How to perform the experiment? A cart placed in front of the motion detector (on the floor), is suddenly pushed away. Another quick kick is given to the cart to let it move toward the motion detector. It can be useful to attach a small piece of carton paper in front of the cart to facilitate the data collection. You need to stop the cart on its way back in order to avoid hitting the motion detector.





Typical trends

s(t): the s(t) trend can be well approximated by a linear increase (positive slope) in the moving away motion and a linear decrease (negative slope) in the moving toward motion after the motion inversion (at approximately 2.40 s). The time intervals where the cart is still, are evident: the first is of about 1.40 s and, when the cart has been stopped, is of about 1.0 s.

v(t): the v(t) trend shows two, almost horizontal, parts, connected by a stepwise inversion that lasted 0.40 s. Due to the initial impulsive push, v(t) changes its value, in a few tens of a second, from zero to a positive value of about 1.0 m/s; this value remains such until the second rapid push inverts the motion. On the way back to the sensor the trend is still constant but negative; notice a slow decrease in the absolute value, due to friction with the floor. The final stop, to avoid hit with the sensor, is well evident in the smoothed step that brings the velocity to zero.

a(t): is essentially zero in the intervals corresponding to a constant v(t) and a linear s(t). The chosen scale shows well the impulsive accelerations that correspond to the initial push (at about 1.50 s), to the kick to invert the motion (at about 2.40 s) and to that to stop the cart (at about 4.00 s).

v(s): the curve is closed because the cart has been accidentally hit at the same position where it had started; otherwise the curve would have been open. The curve is build clockwise, due to the convention used for the reference system (distances increase as one moves away from the motion detector/ origin). The shape resembles that of a rectangle since the motion typical of motion away and toward have almost constant velocity. It is not symmetrical with respect to the position axis because the velocity, in the going away motion, is, on average, greater than in the moving toward motion. The little reduction of the velocity due to the friction with floor is well evident

Notes.

This experiment can help to:

a)clarify the concept of impulsive accelerations (and forces), due to the hit given to the cart, and the final stop, and its representation in the v(t) and a(t) graphs;

b) investigate on the common idea that moving bodies posses a "thrust" force that is consumed while the body proceeds;

c) investigate on how a situation with little friction can determine a slow decrease in the velocity;

d) make a comparison with the toward away motion of a moving person in front of the MD (see experiment "Student walking: going away, stop, and coming back"): the two s(t) are substantially similar (linear trend), but in the v(t) graph here there are no modulations around a quasi constant value, due to the steps.

If the goal of the lesson is that of discussing the ideal motion free of damping effects, one can discuss this difference and also how to perform an experiment where friction is more and more negligible.

It is useful to repeat the experiment on different tracks or on the floor. One can use toy cars with wheels of different quality. When friction increases, s(t) deviates from its linear trend, and tends to a curve with its concavity down; v(t) does not have intervals where it is constant, while a(t) (beside the impulsive phases) tends to constant, and different from zero, values.

This experiment favours the comprehension of the difference between familiar motions, where friction plays a major role and the abstract situations without friction, usually treated in textbooks; allows to compare the experiments on a well known motion, which gives "dirty" graphs, (see Student walk..) and the simplicity of the ideal model of a point – like body that moves on a rectilinear track with no friction.

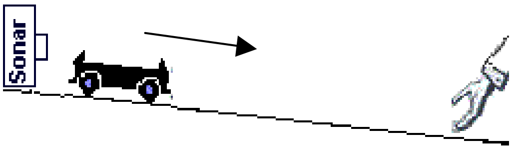
Paper and pencil works It is useful to involve students in activities of graphical analysis, on printouts of results of the experiments they have done or on the above graphs. Examples (not in order of priority):

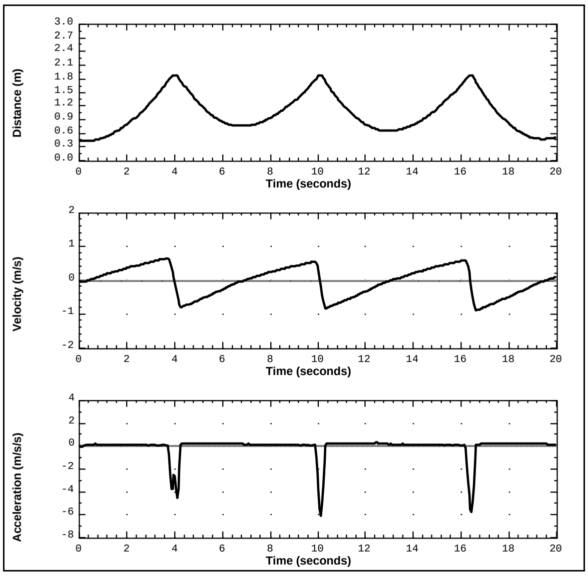
- compare and comment the slope in going away motion phase with the moving toward one;
- evaluate the average velocity in the two phases and compare it with the value given by the software;
- fix a value of time in the three s(t). v(t), an a(t) graphs and describe in words what is read in each of them;
- estimate, from the v(t) and a(t) graphs the duration of the rapid push and compare it with that estimated from the v(s)graph.

Use also for: in dynamics, when addressing impulsive accelerations and forces, elasticity and anelasticity of hits.

5. Cart moving up and down on a ramp (motion detector on top)

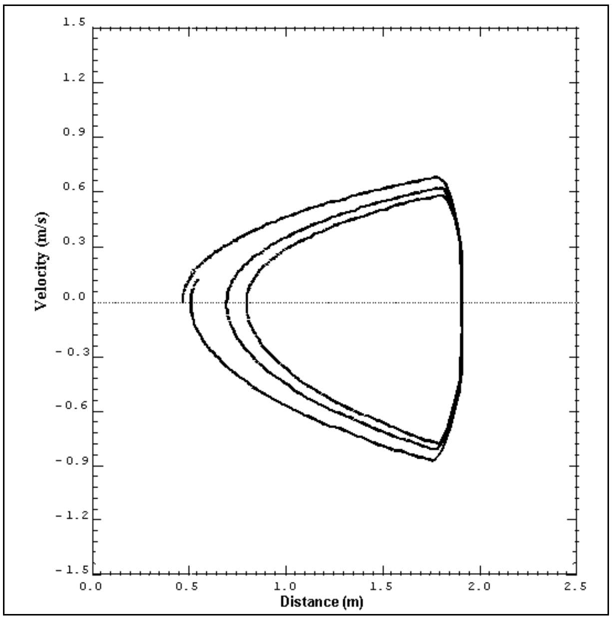
What do you need? A motion detector, a long ramp (about 2 m), a cart
How to perform the experiment? The motion detector is on the top of the inclined ramp. The cart, initially held at rest at about 40 cm from the sensor, is released and falls along the ramp. Every time it reaches the bottom of the plane it is kicked toward the top and when it comes back, it is given another rapid push. It can be useful to attach a piece of carton paper in front of the cart to facilitate the data collection. A slight slope (< 15°) of the ramp should be used in order not to have a too fast motion.





Typical trends

s(t): each descent and ascent is represented by a parabolic s(t), with concavity up, as the motion detector is on the top of the ramp, and also because the cart starts at the top (at about 0.450 m from it). The first part is a going away motion from the sensor. The parabolas are connected through a very narrow horizontal segment (inversion of motion due to the rapid kick). The interaction between the hand and the cart has finite duration (0.25 s), so the peak is not sharp, whereas in a ideal motion the inversion would be instantaneous. The first hand's push, at about 4.00 s produces a velocity of about –0.77 m/s (the cart's approaching the sensor). The first natural inversion of motion at 6.80 s, happens when the cart reaches the highest height (minimum distance to the sensor), about 0.790 m from the sensor and corresponds to the minimum of the corresponding parabola (the same obviously happens also for the second cycle of ascending and descending). The second hand's push (inversion at 10.35 s) produces an initial velocity slightly bigger than the first push (about –0.84 m/s against –0.77 m/s) and therefore the cart reaches an higher quote (a smaller distance, about 0.680 m, to the motion detector).
v(t): during the descent (going away from the sensor) the velocity is positive, while during the ascent (going toward the sensor) is negative. The trend is substantially linear. Due to the choice of the scale the variations of slope between ascent and descent due to friction, are not evident. The linear parts of v(t), that corresponds to each s(t) parabola are connected through smooth steps of negative slope representing the rapid pushes given to the cart to turn back to the motion sensor.
During each cycle of ascend and descend, the slope of the velocity is always positive and correspondingly the concavity of s(t) is always



towards the top.
The slope of v(t) is about 0.3 m/s^2. The smooth steps of the pushes have negative slopes (on the average -5 m/s^2 and show the rapidity of the variation of v(t): they depend on the reflexes of the operator who gives the push and last about 0.52 s for the first, 0.45 s for the second and the third push).

a(t): The acceleration is constant, positive and is about 0.3 m/s^2. The slope of the plane is therefore about 2°. The rapid pushes are well visible: they appear as negative “peaks” since the cart is suddenly braked by the finger of the operator. The first peak is at 4.10 s of about – 4 m/s^2 , the second peak is about at 10.20 s, is narrower than the first, (coherently the smooth step in v(t) is steeper) and its value is -6 m/s^2. The last peak is centred at 16.45 s and its value is about –6 m/s^2.

v(s): The curve is build clockwise, the beginning of the motion corresponds to an initial position of the cart at about 0.400 m from the motion detector and an initial velocity of about 0 m/s (the cart is left to fall free). It should be noted as the shape of this curve, due to the linear dependence of v on time, differs from that of Exp.2, where v is almost constant

Notes.
With this experiment it is possible to clarify:
a) the incorrect idea of a “force due to the push” embedded in the body and “consumed” during the ascent can be addressed through an analysis of the a(t) graph;
b) relation between the slope of a ramp and the component of gravity acceleration along the plane;
c) the influence of the reference system (position of the motion detector) on the shape of the graphs
d) the difference between the parabolic shape of s(t) for a motion with constant and the rectilinear trajectory (note also that often the parabolic shape of s(t) is confused with the parabolic trajectory of a projectile);
e) a impulsive acceleration corresponding to a very rapid push and its relations to impulsive forces;
f) relation between the initial push and the initial velocity
g) the meaning of the area underneath the peak of the impulsive acceleration and its relation with the rapidity and intensity of the push;
h) the correlation between the centre of the peak of the impulsive acceleration and the zero in v(t).
It is useful to have the students make prediction about the v(t) graph from s(t); this tasks allows to address the idea that an inversion is represented by a discontinuity in the graph.
It is useful to repeat the experiment varying the slope of the ramp: qualitatively it can be seen that the more the plane in inclined the more the motion is fast; quantitatively the acceleration can be measured from a(t) graph or from the v(t) slope and can be related to the angle of inclination. Two limits can be discussed: inclined plane at 90° and horizontal plane. It is useful to repeat the experiment with the same plane inclination and with the sonar at the bottom of the ramp (taking care of pushing so that the motion detector does not “see” the hand) and to clarify the influence of the reference system. While the physical phenomenon is invariant, the three graphs s(t), v(t), a(t)

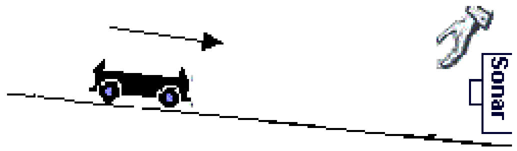
change: v(t) and a(t) reflect with respect to the time axis, s(t) with respect to a line parallel to the time axis, since the motion detector does not measure negative positions. The trend of s(t) is still parabolic (with the concavity down), that of v(t) is still linear (negative), a(t) is still constant (the sign changes). The difference between the arbitrariety of the reference system (motion detector on top or bottom of the ramp) and invariance of the physics aspects (constant acceleration, linear velocity, quadratic s(t)) should be addressed.
It is possible moreover to address a common learning difficulty related to the idea that the acceleration of the ascending motion is different (negative) from that of the descending motion (positive). From the data it is evident that both in descending and ascending motion a(t) has always the same sign. With the same inclination, it is helpful to repeat the experiment with planes more or less rough and to discuss intuitive ideas on friction and its effect.

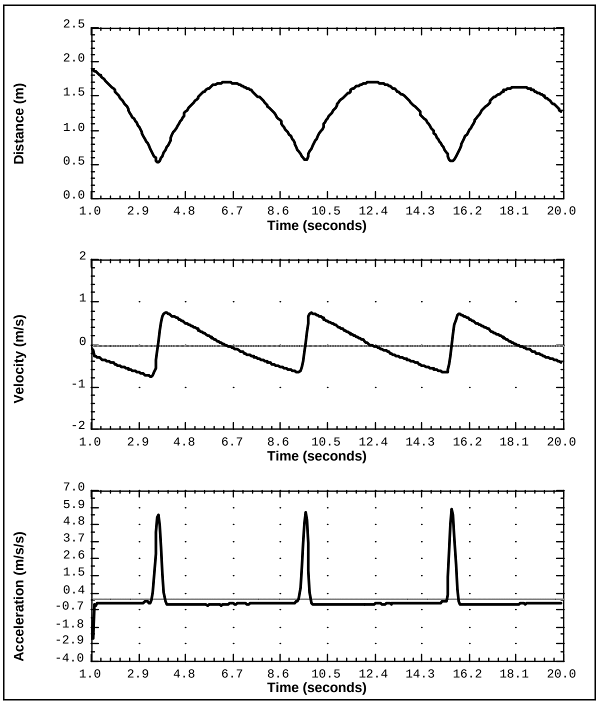
Paper and Pencil Works

It is useful to involve students in graphical analysis of hard copies of experiments outcomes.
Examples of activities are:
- estimate acceleration values from the slope of v(t) and from a(t) and compare the corresponding results;
- measure the inclination of the plane and compare it with what can be found experimentally from acceleration;
- estimate the inversion instants, distinguish between spontaneous inversions and induced ones;
- estimate the duration of inversion from v(t) and a(t);
- measure highest height reached by cart and relate it with initial velocity;
- identify symmetry in s(t), v(t) v(s);
- identify from v(s) initial condition for each going up/down motion

6. Cart moving up and down on a ramp (motion detector at the bottom)

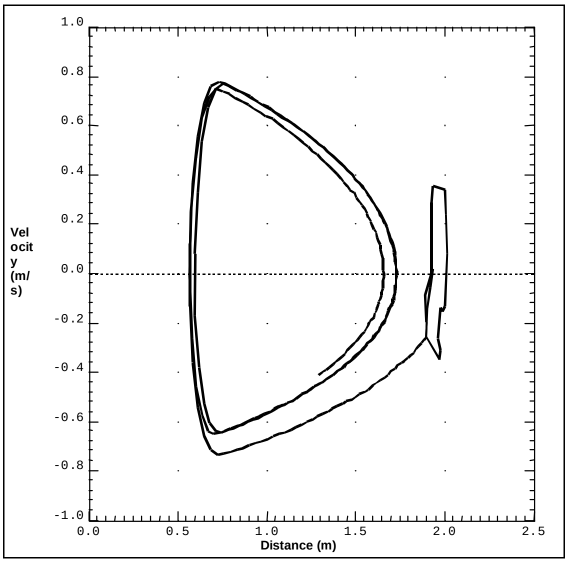
What do you need? A motion detector, a long ramp, a cart
How to perform the experiment? The motion detector is on the bottom of the inclined plane. The cart, initially at rest at about 2 m from the bottom of the ramp is released so that it can to freely move along the ramp; before reaching the bottom it is rapidly kicked toward the top and every time it turns back, it is given another rapid kick. It can be useful to attach a small piece of carton paper in front of the cart to facilitate the data collection. A slight slope (< 15°) of the ramp should be used in order not to have a too fast motion. Take care on how you push in order not to have the motion detector “see” the hand). It is also recommended that the kicks be not too strong, in order to have the cart invert his motion before to reach the top of the ramp.





Typical trends

s(t): each ascent and descent is represented by a parabolic s(t), with concavity toward the bottom: actually the motion detector is on the bottom of the ramp, the cart starts at 1.920 m from the bottom of the plane (where the sonar is) and there is first a descent and then an ascent.
The parabolas connected through a narrow horizontal segment (inversion of motion due to the rapid push of the hand). The interaction between the hand and the cart has finite duration (0.15 s).
It should be made clear that the natural inversion of motion, happening when the cart reaches the highest height, corresponds to the maximum distance from the motion detector. The first hand’s push (inversion at 3.70 s) produces a velocity of about + 0.78 m/s. By chance in this experiment the second and third push (respectively at 9.65 s and 15.55 s) produced the same initial velocity and therefore almost the same highest height.
v(t): during the descent (going toward the sensor) the velocity is negative, while during the ascent (going away from the sensor) is positive. The trend is substantially linear; due to choice of scale the variation of slope between ascent and descent, due to friction, is not evident. The linear parts of v(t), in correspondence to each parabola are connected by fast steps representing the rapid pushes given to the cart.
It should be addressed that the slope is always negative (with the motion detector on the bottom of the ramp the motion is first a going toward then a going away one and so on) and the corresponding concavity of s(t).
The slope of v(t) is on the average, for each cycle of ascend and descend, about – 0.3 m/s^2. The slope



during the inversions is on the average 6 m/s^2.

a(t): The acceleration is constant, negative and its module is 0.2 m/s^2. The slope of the plane can be calculated to be about 1°. The rapid pushes are well visible: they appear as positive "peaks" since the cart is suddenly accelerated by the hand of the operator. The first peak is centred around 3.75 s (its value is about 5 m/s^2), the second peak is at 9.65 s (its value is about 6 m/s^2), the last peak is at about 15.50 s (value is 6 m/s^2) and it is very similar to the first.

v(s): The curve is build clockwise, the beginning of the motion corresponds to an initial position of the cart at about 2 m from the motion detector and an initial velocity of about 0 m/s.

The second and third push produce the same highest height and then the two curves are superimposed.

Notes.

With this experiment it is possible to clarify:

a) the idea of a "force due to the push" embedded in the body and "consumed" during the ascent can emerge, through an analysis of the a(t) graph;

b) relation between the slope of a ramp and the component of gravity acceleration along the plane;

c) the influence of the reference system (position of the motion detector) on the shape of the graphs

d) the difference between the parabolic shape of s(t) for a motion with constant and the rectilinear trajectory (note also that often the parabolic shape of s(t) is confused with the parabolic trajectory of a projectile);

e) a impulsive acceleration corresponding to a very rapid push and its relations to impulsive forces;

f) relation between the initial push and the initial velocity

g) the meaning of the area underneath the peak of the impulsive acceleration and its relation with the rapidity and intensity of the push;

h) the correlation between the centre of the peak of the impulsive acceleration and the zero in v(t).

It is useful to have the students make prediction about the v(t) graph from s(t); this tasks allows to address the idea that an inversion is represented by a discontinuity in the graph.

It is useful to repeat the experiment varying the slope of the ramp: qualitatively it can be seen that the more the plane in inclined the more the motion is fast; quantitatively the acceleration can be measured from a(t) graph or from the v(t) slope and can be related to the angle of inclination. Two limits can be discussed: inclined plane at 90° and horizontal plane.

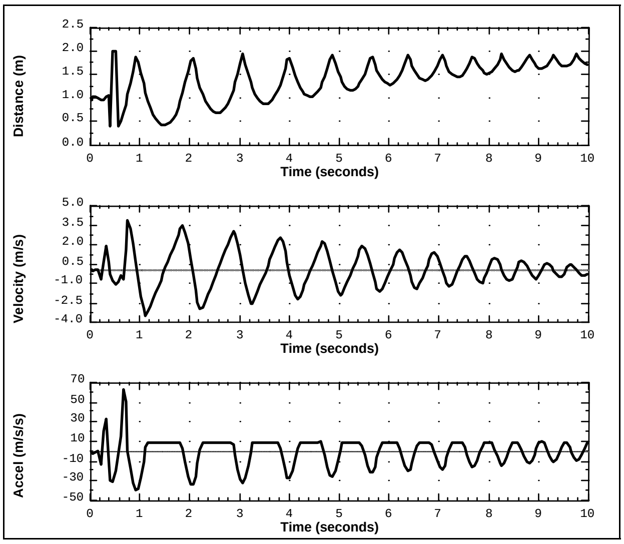
It is useful to repeat the experiment with the same plane inclination and with the sonar at the top of the and to clarify the influence of the reference system. While the physical phenomenon is invariant, the three graphs s(t), v(t), a(t) change: v(t) and a(t) reflect with respect to the time axis, s(t) with respect to a line parallel to the time axis, since the motion detector does not measure negative positions. The trend of s(t) is still parabolic (with the concavity up), that of v(t) is still linear (positive), a(t) is still constant (the sign changes). The difference between the arbitrariety of the reference system (motion detector on top or bottom of the ramp) and invariance of the physics aspects (constant acceleration, linear velocity, quadratic s(t)) should be addressed.

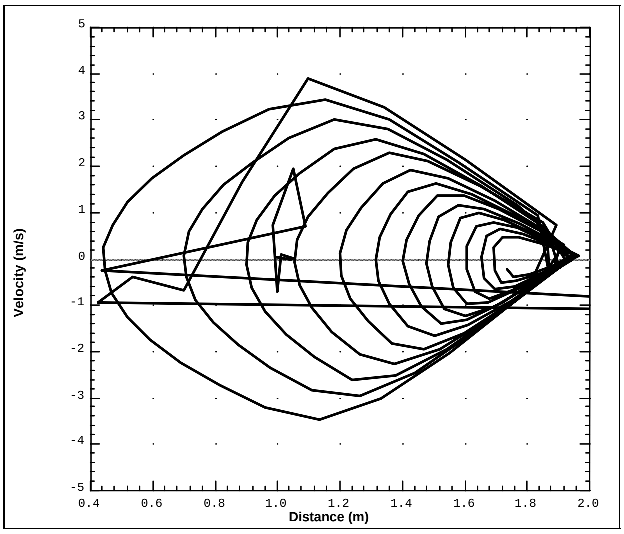
It is possible moreover to address a common learning difficulty related to the idea that the acceleration of the ascending motion is different (negative) from that of the descending motion (positive). From the data it is evident that both in descending and ascending motion a(t) has always the same sign. With the same inclination, it is helpful to repeat the experiment with planes more or less rough and to discuss intuitive ideas on friction and its effect.

Paper and Pencil Works: it is useful to involve students in graphical analysis of hard copies of experiments outcomes. Examples of activities are:
- estimate acceleration values from the slope of v(t) and from a(t) and compare the corresponding results.
- measure the inclination of the plane and compare it with what can be found experimentally from acceleration;
- estimate the inversion instants, distinguish between spontaneous inversions and induced ones, estimate the duration of inversion from v(t) and a(t);
- measure highest height reached by cart and relate it with initial velocity;
- identify symmetry in s(t), v(t) v(s).
- identify from v(s) initial condition for each going up/down motion

7. Bouncing of a ball on a smooth floor

What do you need? A motion detector, a smooth floor, a small ball.
How to perform the experiment? A student on a chair holds the motion sensor and another lets the ball fall on the floor from beneath the sensor. It is advisable to use a smooth part of the floor in order not to have the ball moving out of the vision cone of the motion detector.





Typical trends

s(t): The motion detector is at about 1.90 m to the floor (approximately). The artefacts of the first half second are due to the hand of student holding the ball; from about 0.50 s on, each ascent and descent is represented by a parabolic s(t), with concavity up. The minima of the parabolas appear, as time goes by, at an increasing distances from the motion sensor (smaller distance from the floor), due to effect of the anelastic bouncing of the ball on the floor. The graph evidently presents “peaks”, connecting two adjacent parabolas, and “valleys”: since the motion is seen from the top, the peaks and the valleys both describe an inversion of the ball motion, the inversion on the floor due to the hit, and the inversion at the maximum height of the ball, respectively. Their visual appearance is rather different as they correspond to different phenomena and it is very useful to point to that, i.e. the peaks represent a very fast event in comparison with the motion inversion in air (at the maximum height reached by the ball). The first bouncing on the floor (corresponding to the first peak) happens at 0.90 s, the second at 2.05 s. The distances from the motion detector vary from 1.870 m to 1.940 m, due to the fact that the sensor is held by hand. The first inversion in air happens at 1.50 s at 0.440 m from motion detector. The distances from the motion detector increase after each bouncing (or, conversely, the maximum reached height decrease) from 0.440 m to 1.670 m.

v(t): during the descent (going away from the sensor) the velocity is positive, while during the ascent (going toward from the sensor) is negative. The trend is substantially linear; the initial artefacts are very well visible, due to the process of numerical approximation used to derive these data from s(t).
The slope of v(t) ranges around 10 m/s^2. It is useful to note that, being the slope always the same during the motion, this corresponds to the same acceleration, even if the maximum and minimum

velocity values decrease after each hit.
a(t): The acceleration is constant, positive and is on the average about 10 m/s^2. The initial "peaks" are due to the motion of the hand seen by the motion detector. It is useful to note that the segments (motion of ball in air) have always the same value. The duration of the motion of the ball in air decreases from a maximum of 0.65 s (after first bouncing) to minimum of 0.05 s (after the last bouncing)
v(s): The irregularities are due to the initial artefacts. The "radius" of the closed curves are reduced after each hit due to the fact that the velocity decreases as the distance from the sensor increases.

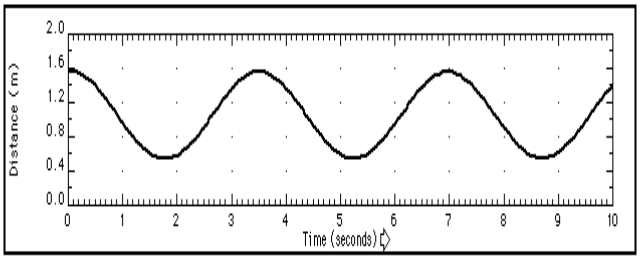
Notes.
With this experiment it is possible to clarify:
a) comparison between natural inversions and induced ones;
b) effect of not ideal elastic hits;
c) the influence of the reference system (position of the motion detector) on the shape of the graphs;
d) the area underneath the peak of the impulsive acceleration gives information on the rapidity and intensity of the hit;
e) the correlation between the centre of the peak of the impulsive acceleration and the zero in v(t);
f) a linear v(t) connected to a constant acceleration;
g) the inversion of motion corresponds to a change in sign of velocity;
h) the change in the sign of velocity is not connected to a change in slope of the velocity itself;
i) confusion between trajectory and s(t).
It is useful to have the students make prediction about the v(t) graph from s(t) , this task allows to address the idea that an inversion is represented by a discontinuity in the graph.

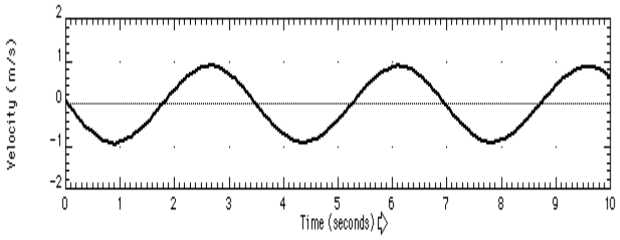
Paper and Pencil Works: It is useful to involve students in graphical analysis of hard copies of experiments outcomes. Examples of activities are:
- estimate acceleration values from the slope of v(t) and from a(t) and compare the corresponding results.
- estimate the inversion instants, distinguish between spontaneous inversions and induced ones, estimate the duration of inversion from v(t) and a(t);
- measure highest height reached by ball;
- identify symmetry in s(t), v(t) v(s).

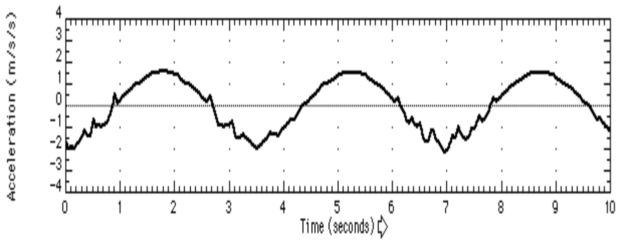
8. Free Oscillations of a Pendulum

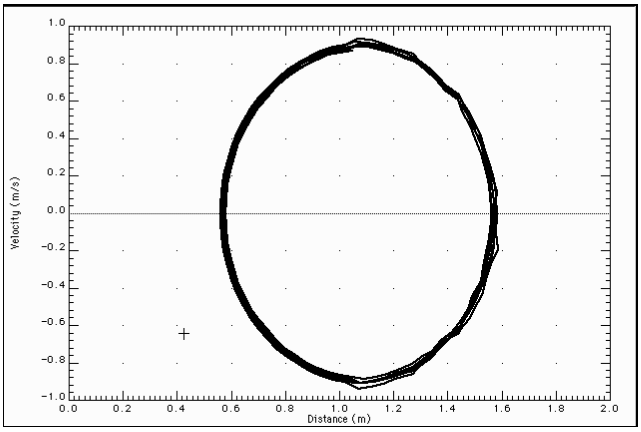
What you need: a small weight, a long wire

How to perform the experiment: Tape the weight to the wire, then attach them to a high rigid support. Then pull lightly the weight and let it start oscillating. Take care to have not the weight go out of the vision cone of the sensor.









Typical trends

s(t): The graph is a sinusoid with amplitude of 0.5 m. The period is about 3.50 s. The length of the wire is then about 3.0 m. The initial position of the weight is at 1.578 m to the sensor, the velocity being 0.09 m/s (the data collection has started after the weight began oscillating).

v(t): the data collection had started when the weight was already oscillating: initial velocity is not zero but 0.09 m/s (positive, the weight was going away to the sonar). The graph crosses the abscissas (v=0) when the weight reaches the maximum amplitude of oscillations. The first maximum of the graph has a value of about 0.94 m/s. A little damping effect can be seen by the values of the other two maximum values, 0.92 m/s and 0.90 m/s respectively.

a(t): the graphs shows irregularities due finite differences method. Initial acceleration is negative and has a value of about –1.7 m/s^2. The maxima have values of about 1.6 m/s^2. It is useful to note that trend is the same of the s(t) graph, changed in sign (while between s(t) and v(t) there is a phase shift of about half period).

v(s): if there was not attenuation in the oscillations, the graph would be that of an ellipses in which the curve are superimposed. Since there is a little damping effect, the ellipses are concentric and the damping effect can be see from the thickness of the curve.

Notes. With this experiment it is possible to address various features of oscillatory motion. First, it is possible to show the damping effect due to the air resistance. It can be useful to vary the initial velocity and position in order to see how this parameters influence the motion. Also the length of the wire connecting the support and the weight can be varied in order to see how this

	influences the period of motion.

Iconic Notes: The initial display that can be used with this experiment is a one s(t) graph; with the experimental setting described above the default display looks like in the following figure:

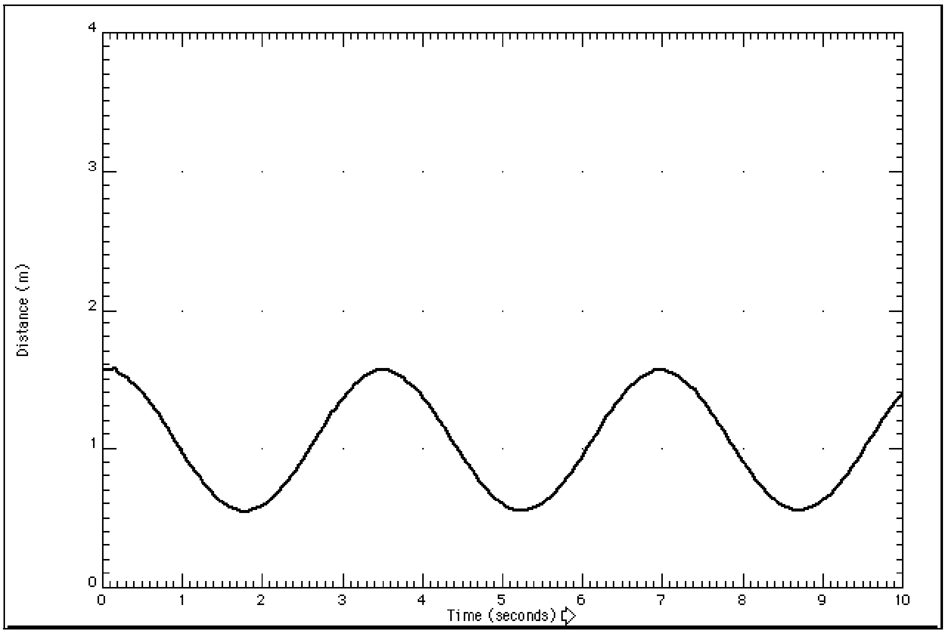


Figure 1: Pendulum oscillations: default display of s(t) graph

The distance scale is not optimised and the graph can be difficult to read, specially the amplitude of the motion. The maximum of the scale should be changed in order to let readers appreciate the amplitude of the motion. Changing the scale, the display will look as in the following figure:

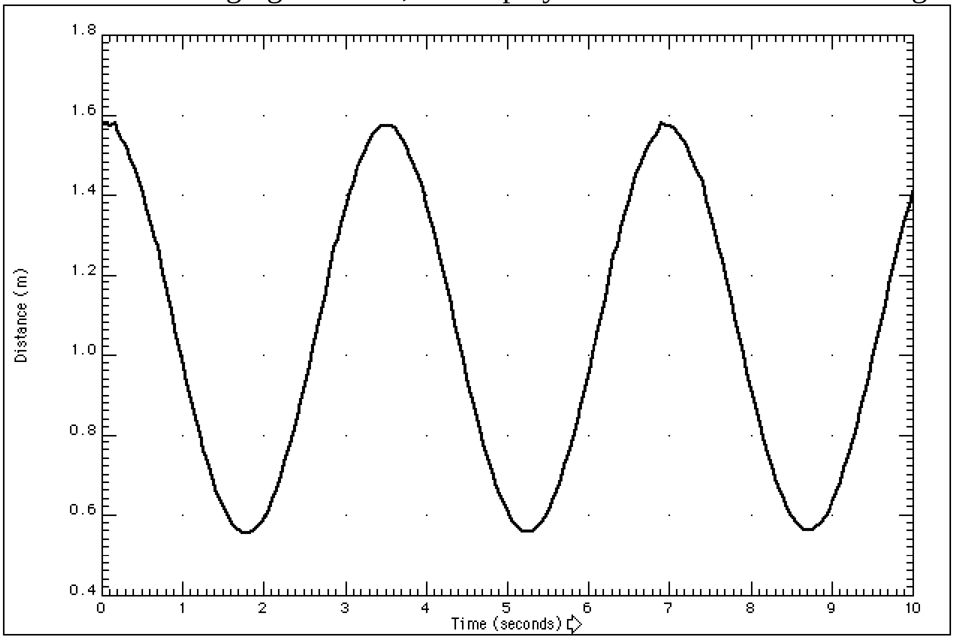


Figure 2: Pendulum oscillations: optimised s(t) graph display for amplitude reading

In this way it is possible to quickly estimate the amplitude as 0.5 m.
From this display it is possible to estimate the period of the oscillations. Using the cursor, it is sufficient to move the cursor to two maxima (or the minima) and read the correspondent value of time. The following figure shows a typical display:

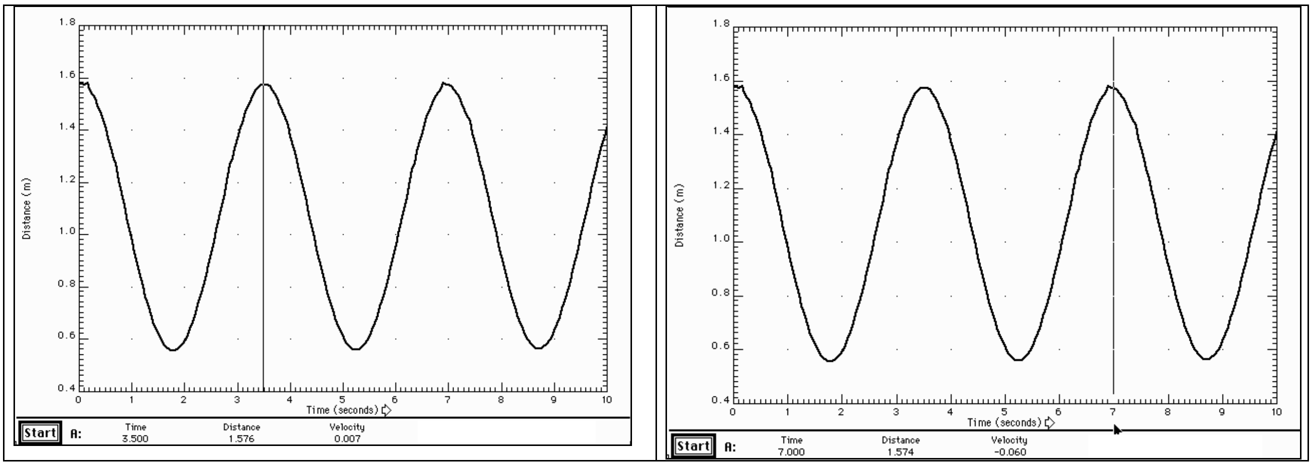


Figure 3: Pendulum oscillations: two s(t) displays to estimate period of oscillations

From the difference between the two time values indicated (7 s and 3.5) an estimation of the period of oscillation is 3.5 s.

Another feature that can be investigate easily is the correlation between s(t) and v(t) graph. Changing to a two graph display, leaving the s(t) graph scales unchanged, the graph will look like in the following figure:

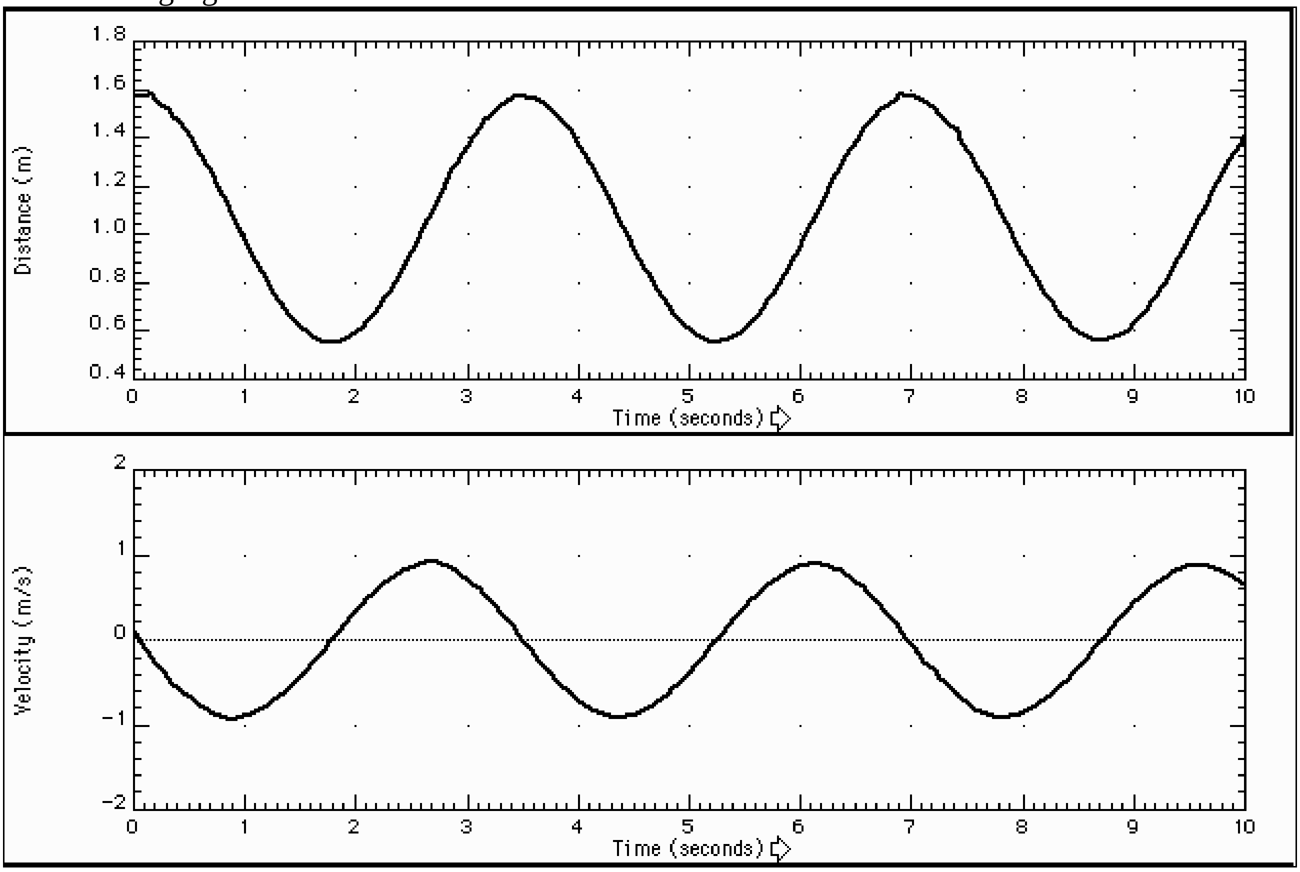


Figure 4: Pendulum oscillations: two graphs display for s(t), v(t) correlation addressing

The velocity scale is not optimised, as s(t) graph. It should be useful ,before addressing correlation, to optimise also the v scale, as in the following figure:

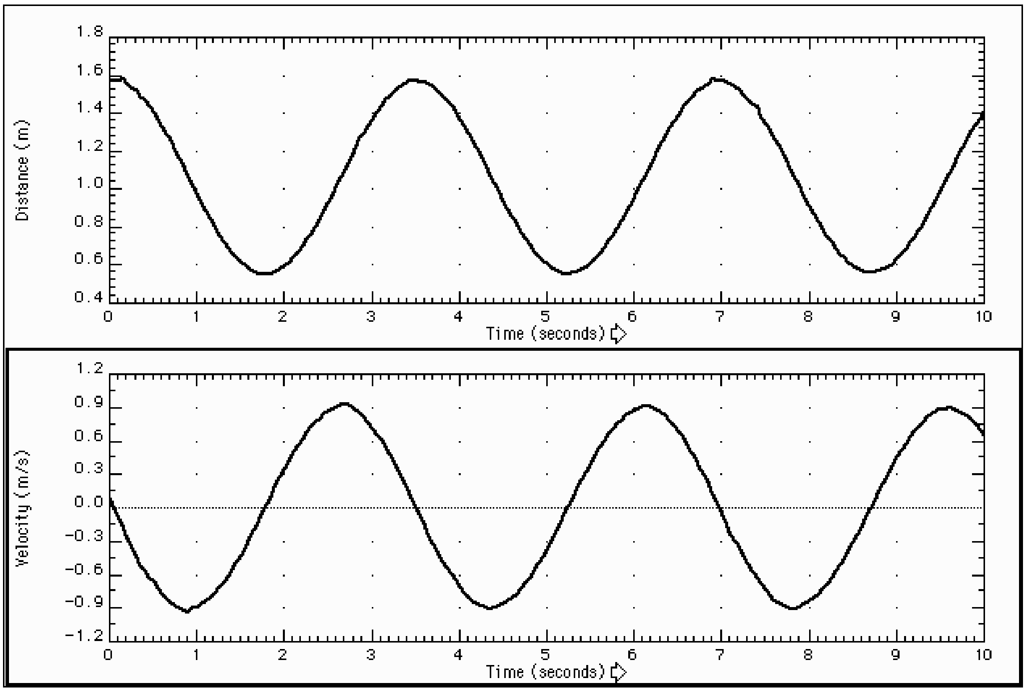


Figure 5: Pendulum oscillations: optimised two graphs display for s(t), v(t) correlation addressing

Now it is possible to use the cursor to address the physics correlation between the two graphs: choosing Analyse function from the menu, it is to move to the zeros of the velocity and see how they corresponds to the maximum amplitudes in the s(t) graphs. A typical display is as in the following figure:

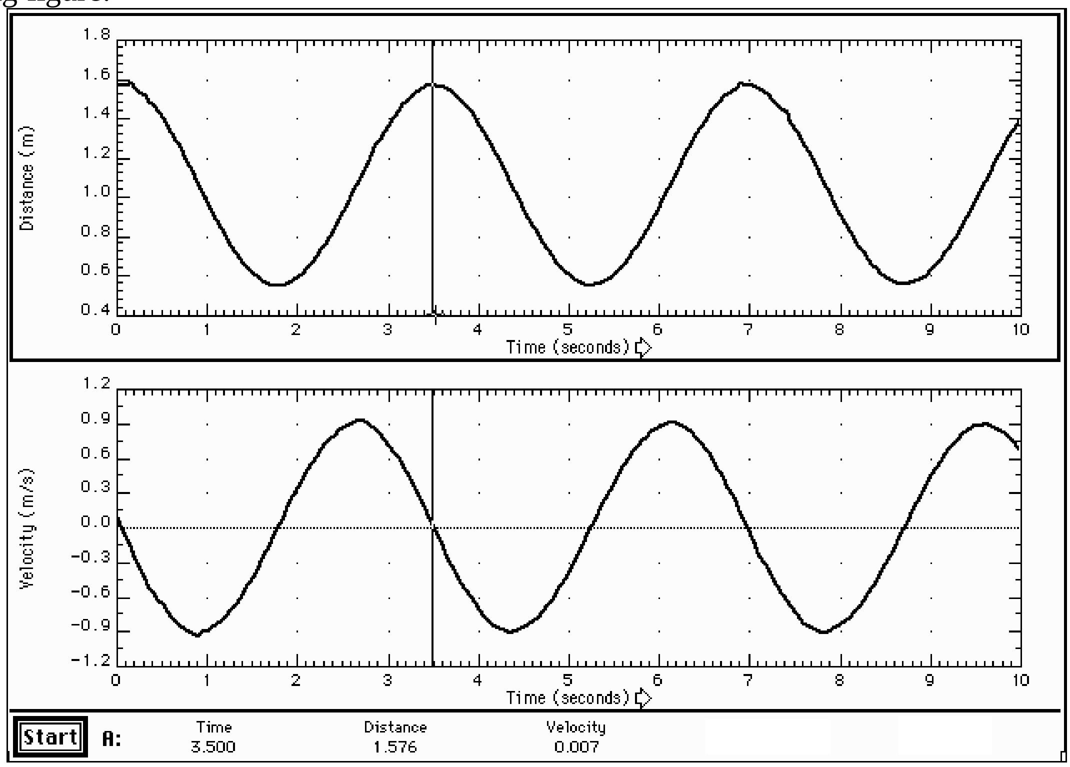


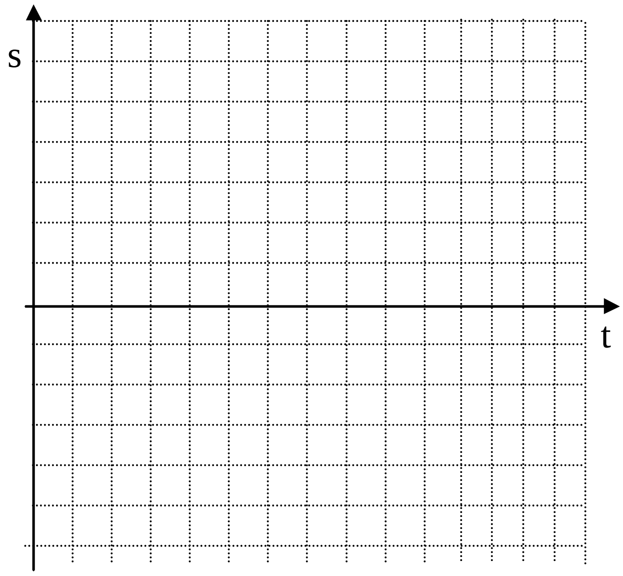
Figure 6: Pendulum oscillations: addressing s(t) and v(t) correlation with the use of cursor.

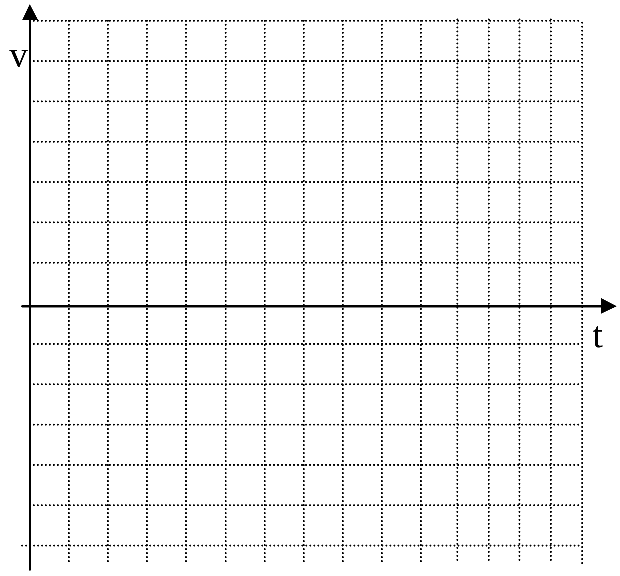
It is useful recall students' attention also on the numerical values indicated at the bottom of the display. Since the accuracy on velocity is almost 0.05 m/s, the value 0.007 m/s indicated by the software has to be considered as a zero value (the uncertainty would be greater then 100%). The correspondent value of s(t) is 1.576 m.

STUDENTS' WORKSHEETS (Path 1)

Students' worksheet #1:Stillness

A1) ***Sonar off****. A student is still in front of sonar and measures his/her distance from sonar with tape-meter* Figure out which would be the s(t) and v(t) corresponding to his/her standing still there and sketch the curves below. Place appropriate measure units and scales on axes.





B1) ***Sonar on.*** *The student being still in the same position as before, the measure is done.* Observe the measured s(t) and v(t) graphs. Draw what you see on the display on the graphs above with a different colour pen, compare them with your predictions and comment carefully, remarking differences/similarities.

B2) Describe, in words, the main features of the experimental s(t) and v(t) graphs (as: kind of curve, trend, artefacts, etc., distinguishing math, physics, pictorial, experimental features)

B3) Which was the students' trajectory in this experiment?

B4) Write about any relation between s(t) and trajectory you think of.

What is the most significant scientific content you have learned today in this activity**?**

What physics/mathematics question is uppermost in your mind as you leave this activity?

Students' worksheet #2: Regular walk: Average velocity estimate from s(t) graph

The experiment is the measure of a regular walking away from the motion detector along a straight line.

A) ***Sonar off.*** *Before the student walks, he/she measures the initial distance s_0 and the final distance s_f of the planned walk away from the sonar.* Write them here (with units)

s_0 =…………………… s_f =………………… $s_f - s_0$ =………………………..

Then the student walks regularly. While he/she is walking, evaluate the duration of the walking by counting. Write here the duration of the walking

T_{tot} = ……………………………….

Now, thinking over the observed walk, figure which could be the s(t) of this motion, and draw it below: use appropriate measure units and scales on axes.

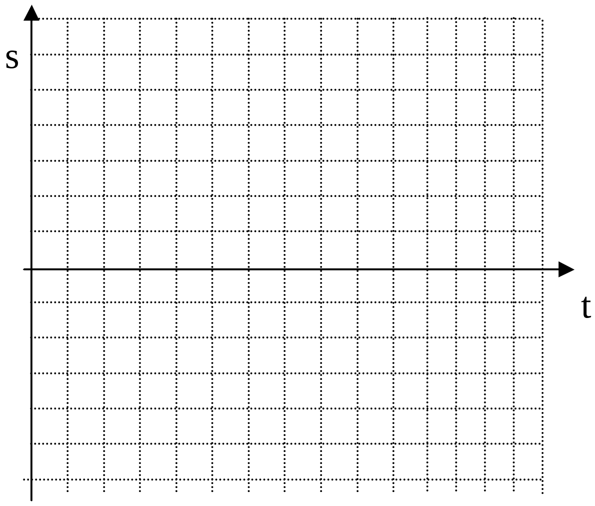


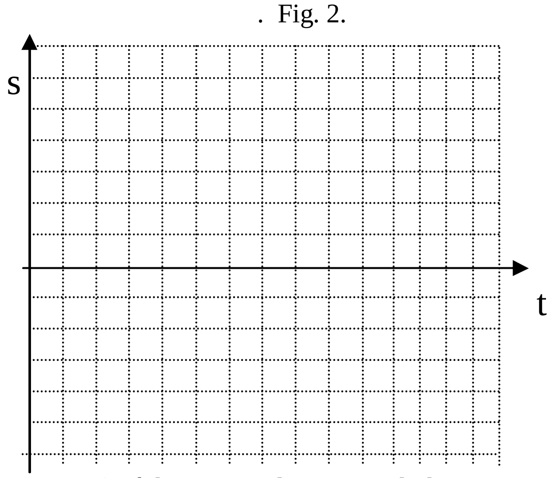
Fig. 1.

A1) Evaluate on the basis of the previous measurements the average velocity of the observed motion.

V_{av} =……………………

B) ***Sonar on.*** *The experiment measures the s(t) of the same student who walks as before between the same positions.* Evaluate again the duration of his motion by counting. Try to walk as in the first part of the experiment. Observe the experimental s(t). Draw what you see on the display on the figure below (place appropriate measure units and scales on axes).

. Fig. 2.



B1) Compare your measure (by counting) of the motion duration with the measure showed by the s(t) graph.

"By counting" T_{tot} = …………………… "Sensor measured" T_{tot} =……………………………….

B2) Estimate the average velocity by using your "by counting" time and the average velocity by using the "sensor measured" time and compare them:

"By counting" V_{av} =…………………… "Sensor measured" V_{av} =……………………

B3) Compare all the average velocities you have calculated until now, also that of part A, and comment the differences and similarities and explain the reasons of the differences/similarities.

B4) Compare the graph of Fig.1 with that of Fig. 2. Comment carefully differences and similarities, and if your prediction is much different from the experimental result sketched in Fig. 2, suggest the possible reasons.

B5) Finally, consider the s(t) of fig. 2: calculate its slope and correlate it to the value of "sensor measured", comment on differences and similarities

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What is the most significant scientific content you have learned today in this activity?

What physics/mathematics question is uppermost in your mind as you leave this activity?

Students' worksheet #3:Trajectory versus s(t)

The experiment is the measure of several regular walks away from the motion detector, each with different modalities velocities.

At the beginning the initial position s_o and the final position s_f from the sonar are measured with the tape meter and all the walks will be in between these two positions.

Write the measured values

s_0 =…………………… s_f =………………… s_f - s_0 =……………

A1***) Sonar on***. A student walks regularly from s_o to $s_{f.}$ Draw in (1) the experimental s(t) (place appropriate measure units and scales on axes)and label it $s_1(t)$

Fig. 1

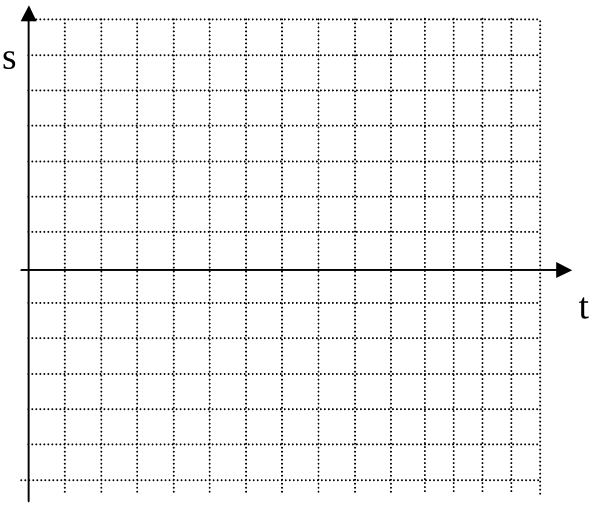
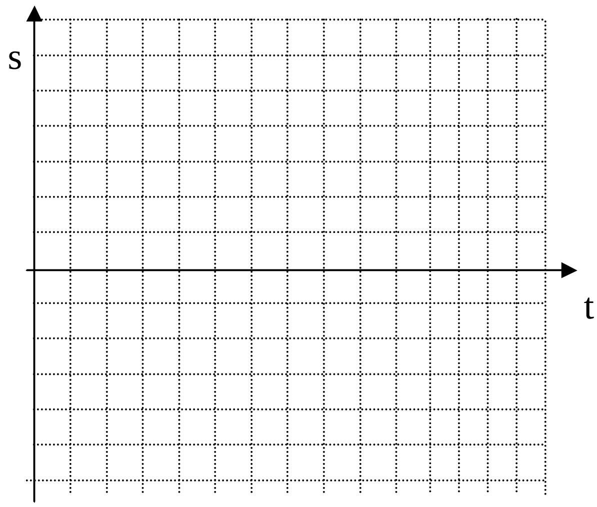


Fig. 2



A3) Describe, in words, the curve s(t) , the motion trajectory, and any relation between these two you may think of.

s(t) --

Trajectory --

Relation s(t)-trajectory. --

B) *The same student walks between the same positions, but going* *<u>faster or slower</u>*. Draw in (1), with a different pen colour, the new s(t) and label it $s_2(t)$.

B1) Did the trajectory change with respect to the previous motion?……………………………………..

……………………………………………………………………………………………………..

B2) Is $s_2(t)$ different from the previous one $s_1(t)$? Explain and comment carefully.

B3) Evaluate the average velocities of the first and second motion, calculating the slope of $s_1(t)$ and $s_2(t)$ over the total time duration

$v_{av\,1}$ =……………………… $v_{av\,2}$ =………………………

B4) Write comments

C) *A students moves between the same positions, firstly going away a while, then stopping a while, and then going away again.*

C1) Which is the trajectory?…………………………………………………………………

C2) Draw in (2) the new measured $s_3(t)$. Is it different from the previous ones? Explain and comment carefully.

What is the most significant scientific content you have learned today in this activity?

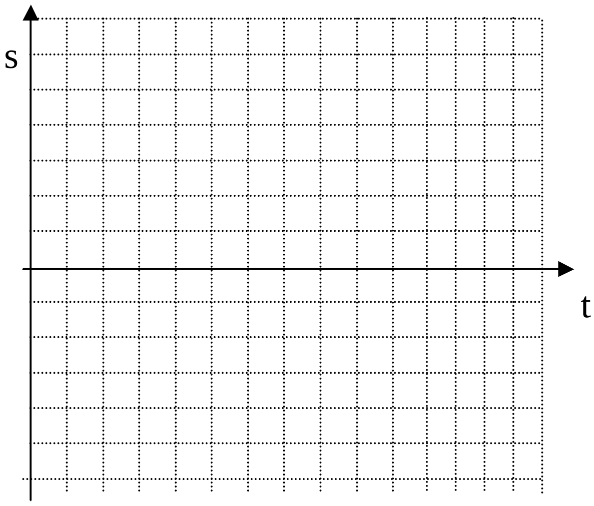
What physics/mathematics question is uppermost in your mind as you leave this activity?

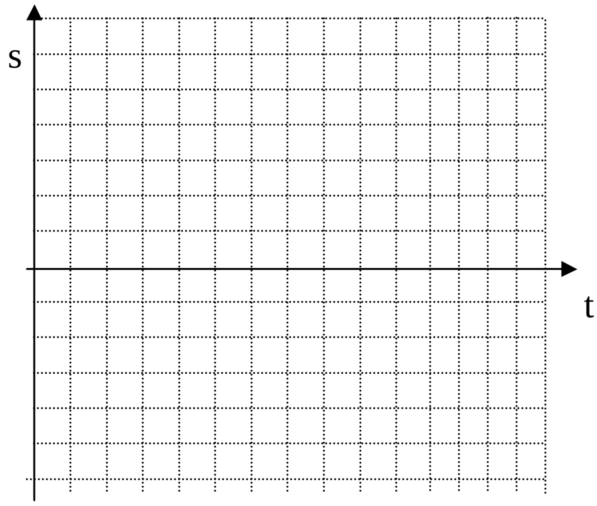
Students' worksheet #4: Regular walk: Average velocity as function of time interval

The experiments are measures of regular walkings away from the motion detector along a straight line. It is required to fix and measure the initial position s_o and the final position s_f from the sonar and to walk always in between them.

A1***) Sonar on****. A student walks from s_o to s_f facing the display and observing the resulting s(t).*
Draw in Fig. 1 the displayed s(t) (place appropriate measure units and scales on axes).

. Fig. 1 Fig. 2





A1) Read from the s(t) graph in Fig. 1 the initial time, the final time, and two other intermediate time values and the corresponding positions and write them in the following table:

Table 1	0 (initial)	1	2	f (final)
t				
s(t)				

Now calculate the following quantities (write also the measure units):

$\langle v\rangle_{10} = (s(t_1) - s(t_0))/ (t_1 - t_0) =$…………………………………………………….

$\langle v\rangle_{21} = (s(t_2) - s(t_1))/ (t_2 - t_1) =$……………………………………………………

$\langle v\rangle_{fo} = (s(t_f) - s(t_0)) / (t_f - t_o) =$……………………………………………………

and comment differences/similarities of these values for average velocity:

B) A student walks regularly between the same distances, firstly going away until the final position, then coming back to the initial one. Draw in Fig. 2 the measured s(t).

B1) Read from the s(t) graph in Fig. 2 the initial, the final and one other time value, the corresponding positions and write them in the following table:

Table 2	0 (initial)	1	f (final)
t			
s(t)			

Calculate the following quantities (write also the measure units):

$\langle v\rangle_{10} = (s(t_1) - s(t_0))/ (t_1 - t_0) =$…………………………………………………….

$<v>_{fo} = (s(t_f) - s(t_0)) / (t_f - t_o) =$…………………………………………………

and comment differences/similarities of these values for average velocity:

C) ***Sonar off.*** *A student walks regularly from s_o to s_f as in A.* Figure out which would be the v(t) graph of this motion and draw it in Fig. 3.

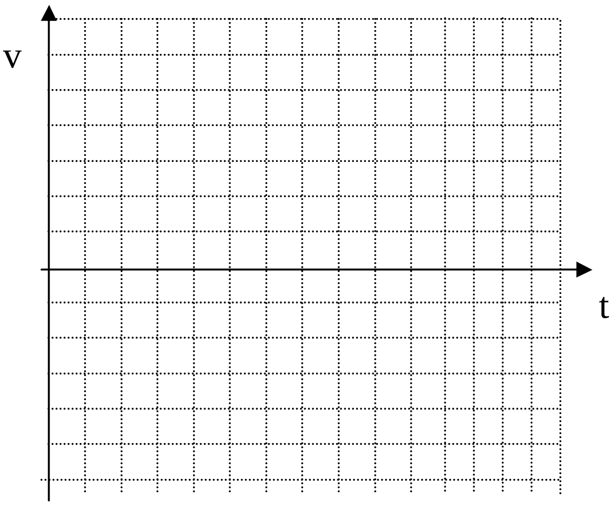


Fig. 3

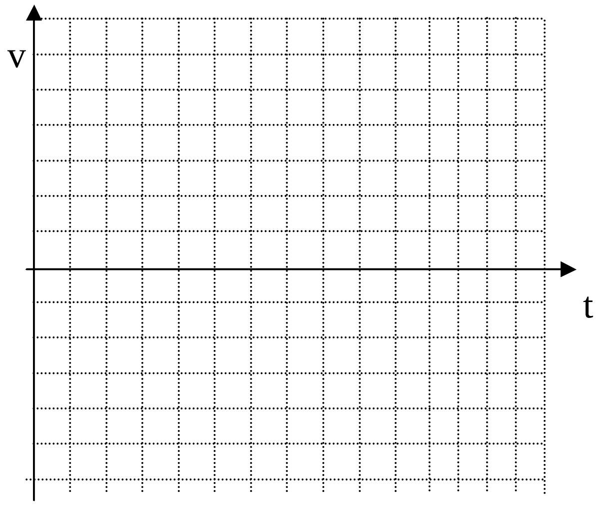


Fig. 4

Sonar on, having chosen a two graph display (with s(t) and v(t)) *a student walks as before.* Draw in Fig. 4 the measured v(t) graph and comment carefully differences and similarities with your prediction (Fig 3).

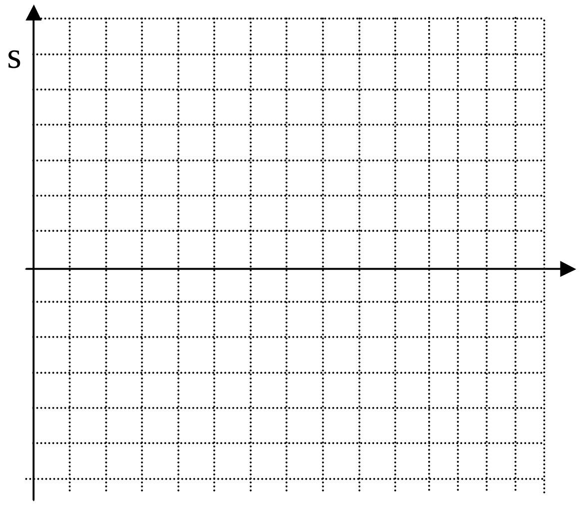
What is the most significant scientific content you have learned today in this activity?

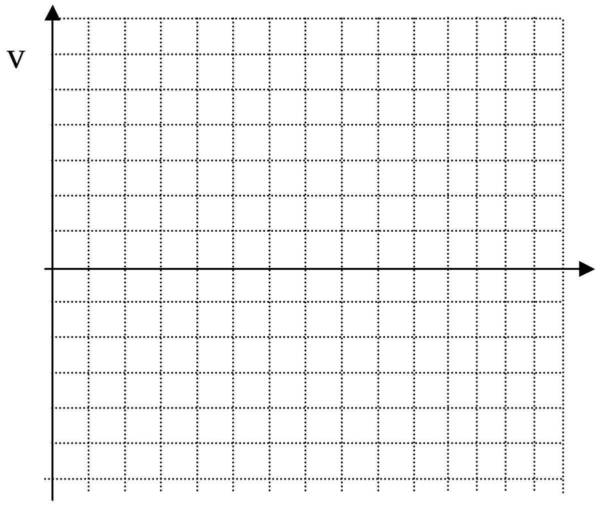
What physics/mathematics question is uppermost in your mind as you leave this activity?

Students' worksheet #5: First velocity fit

The experiments are measures of regular walkings away from the motion detector along a straight line. It is required to decide the initial position s_o and the final position s_f from the sonar and to walk always in between them.

A) ***Sonar off****. A student walks from s_o to s_f.* Figure out which would be the s(t) and v(t) graphs of this motion and sketch them below.





A1) ***Sonar on (2 graphs display s(t), v(t)).*** *A student walks as before from s_o to s_f.* Draw in the above graphs, with a different colour pen, the displayed s(t) and v(t) (using appropriate measure units and scales on axes). Comment carefully differences and similarities with your predictions.

A2) Explain what are the "bumps" in the experimental v(t) graph.

A3) From the experimental s(t) and v(t) graphs read the initial and the final time, and two other intermediate time values, the corresponding s(t) and v(t), and write them in the following table:

Table 1	0 (initial)	1	2	f (final)
t				
s(t)				
v(t)				

Now calculate the following quantities (writing the measure units):

$\langle v \rangle_{10} = (s(t_1) - s(t_0))/ (t_1-t_0) =$……………………………………………………….

$\langle v \rangle_{21} = (s(t_2) - s(t_1))/ (t_2-t_1) =$………………………………………………………

$\langle v \rangle_{fo} = (s(t_f) - s(t_0)) / (t_f - t_o) =$………………………………………………………

A3) Compare the value $v(t_1)$ with $\langle v \rangle_{21}$ and $\langle v \rangle_{10}$ and comment carefully

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A3) Compare the value $v(t_2)$ with $<v>_{20}$ and comment carefully

----

A5) Calculate the quantity $<v> = (v(t_0) + v(t_1) + v(t_2) + v(t_f)) / 4$, arithmetic mean of the four velocity values. Explain every relation you see between $<v>$ and $<v>_{f0}$

A7) Draw on the experimental v(t) graph a straight line representing the value of $<v>$. Can it approximate the average velocity $<v>_{f0}$? Comment carefully.

What is the most significant scientific content you have learned today in this activity?

What physics/mathematics question is uppermost in your mind as you leave this activity?

Students' worksheet #6: **Negative velocities**

The experiment to be performed is to ***walk towards*** *the motion detector with regular steps following a straight path. . It is required to decide the initial position s_o and the final position s_f from the sonar and to walk always in between them.*

A) ***Sonar off.*** *A students walks regularly from s_o to s_f towards the detector.* Figure out which would be the s(t) and v(t) graphs and sketch them below using appropriate measure units and scales on axis.

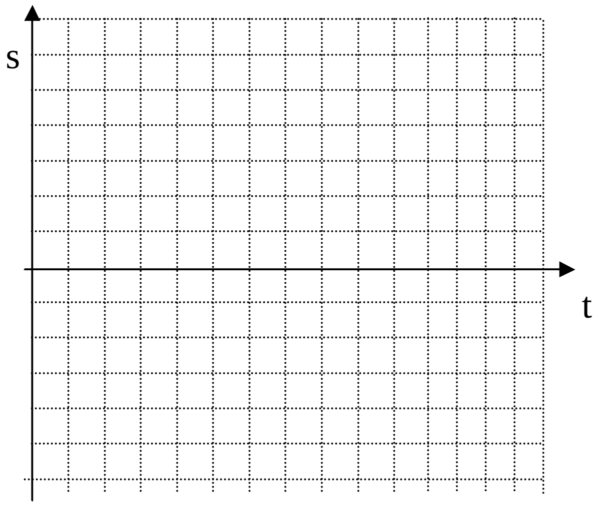


Fig. 1

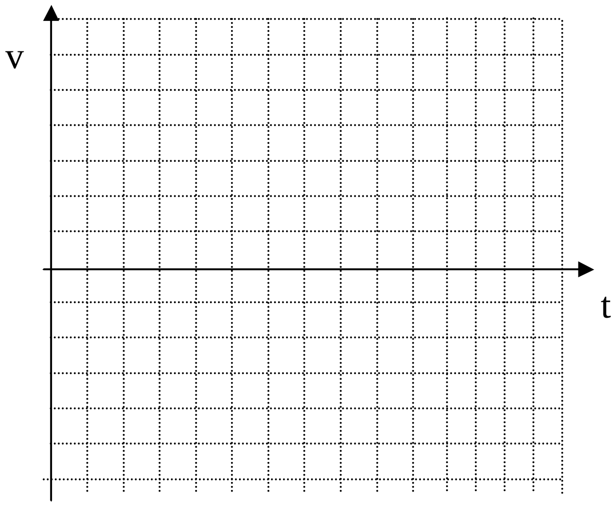


Fig. 2

B) ***Sonar on (2 graphs display s(t), v(t)).*** *A students walks regularly from s_o to s_f towards the detector as before.* Observe the measured s(t) and v(t) graphs, draw them with a different colour pen above, compare them with your predictions and comment.

B1) Describe, in words, the experimental s(t) and v(t) graphs.

B2) Explain why the velocity is negative and comment.

B3) From the experimental s(t) and v(t) graphs , read the initial and the final time and two other intermediate time values, the corresponding s(t) and v(t), and write them in the following table:

	0	1	2	f
t				
s(t)				
v(t)				

B4) Calculate the following quantities (write the measure units):

$<v>_{10}= (s(t_1) - s(t_0))/ (t_1-t_0) =$……………………………………………………….

$<v>_{21}= (s(t_2) - s(t_1))/ (t_2-t_1) =$………………………………………………….

$<v>_{fo}= (s(t_f) - s(t_0)) / (t_f- t_o) =$………………………………………………….

B5) Compare the value $v(t_2)$ with $<v>_{21}$ and comment carefully

----

B6) Calculate the quantity $<v> = (v(t_0) + v(t_1) + v(t_2) + v(t_f)) / 4$, arithmetic mean of the four velocity values. Explain every relation you see between $<v>$ and $<v>_{f0}$

B7) Draw on the v(t) graph a straight line representing the value of $<v>$. Can it approximate the average velocity of the walk? Comment carefully.

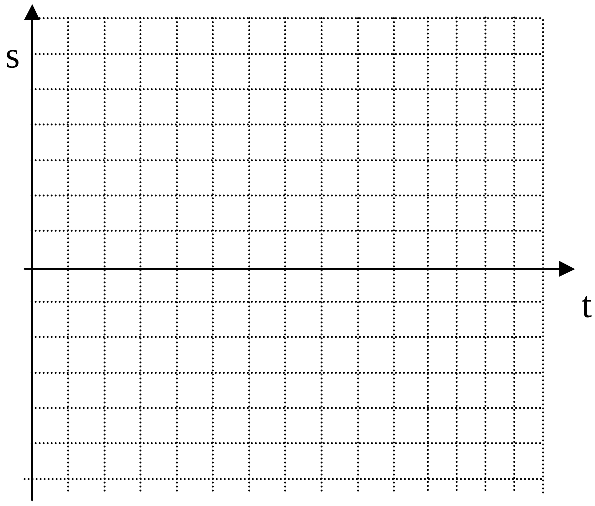
What is the most significant scientific content you have learned today in this activity?

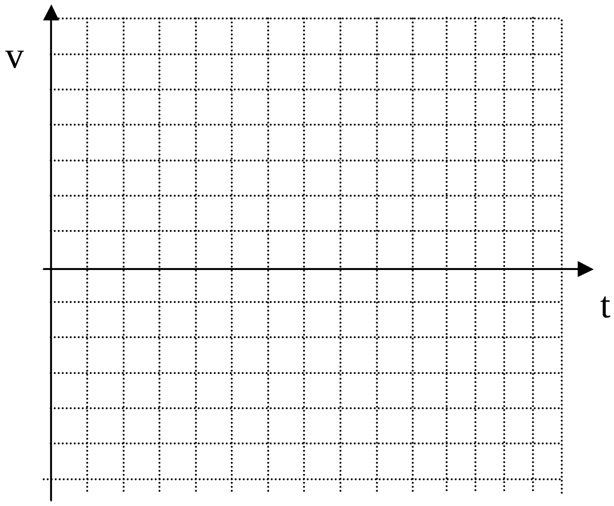
What physics/mathematics question is uppermost in your mind as you leave this activity?

Students' worksheet #7: A first summary on regular walks

The experiment is the measure of a regular walk ***towards and away (or the reverse)*** *from the motion detector with a short stop in between The trajectory is a straight line going from an initial distance s_o to a final distance s_f (both measured with a tape meter). When coming back, it is required to reach the initial position.*

A) ***Sonar off.*** *A students walks regularly from s_o to s_f and comes back* Figure out which would be the s(t) and v(t) graphs and sketch them below using appropriate measure units and scales on axis.





B) ***Sonar on (2 graphs display s(t), v(t)).*** *A students walks regularly from s_o to s_f as much as possible as before.* Observe the measured s(t) and v(t) graphs, draw them with a different colour pen in the above graphs, compare them with your predictions and comment.

B1) Describe, in words, the experimental s(t) and v(t) graphs.

B2) From the experimental s(t) and v(t) graph , read the initial and the final time, two other intermediate time values, the corresponding s(t) and v(t), and write them in the following table:

	0	1	2	f
t				
s(t)				
v(t)				

B4) Calculate the following quantities (write the measure units):

$\langle v\rangle_{10} = (s(t_1) - s(t_0))/ (t_1 - t_0) =$…………………………………………………….

$\langle v\rangle_{21} = (s(t_2) - s(t_1))/ (t_2 - t_1) =$……………………………………………………

$\langle v\rangle_{fo} = (s(t_f) - s(t_0)) / (t_f - t_o) =$……………………………………………………

B5) Compare the value $v(t_2)$ with $<v>_{21}$ and comment carefully

B6) Calculate the quantity $<v> = (v(t_0) + v(t_1) + v(t_2) + v(t_f)) / 4$, arithmetic mean of the four velocity values. Explain every relation you see between $<v>$ and $<v>_{f0}$

B7) Draw on the v(t) graph a straight line parallel representing the value of $<v>$. Can it approximate the average velocity of the walk? Comment carefully.

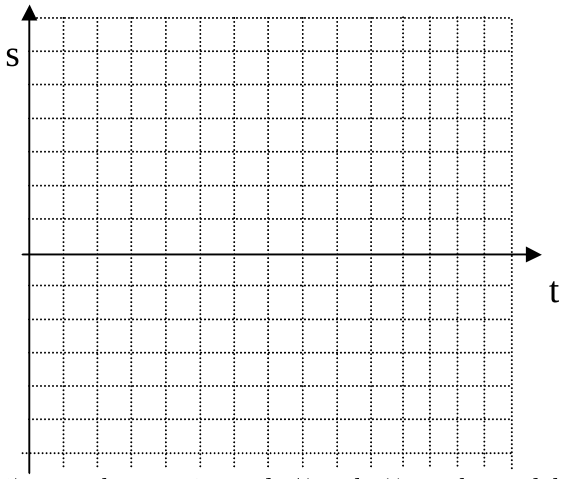
What is the most significant scientific content you have learned today in this activity?

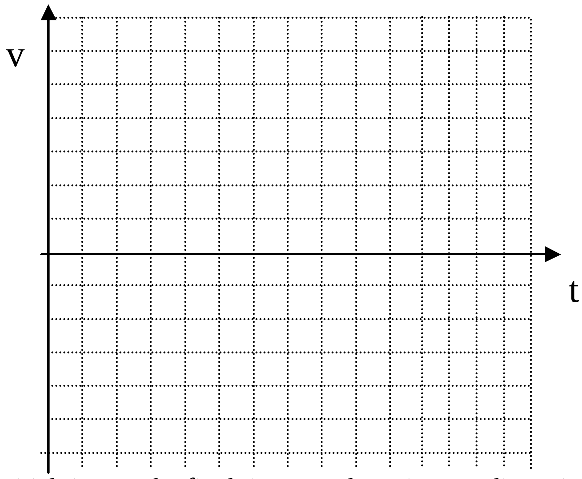
What physics/mathematics question is uppermost in your mind as you leave this activity?

Students' worksheet #8: First modelling of a regular walk

The experiment is the measure of a regular walk ***toward*** *(or away from) the motion detector. The trajectory is a straight line going from a chosen and measured initial distance s_o to a final distance s_f (both measured with the tape meter).*

A) ***Sonar on. (2 graphs display s(t), v(t)).*** *A students walks regularly from s_o to s_f.* Draw the measured s(t) and v(t) in the following graphs (using appropriate measure units and scales on axes)





B1) From the experimental s(t) and v(t) graph , read the initial time t_0, the final time t_f and one intermediate time value t_A, the corresponding experimental s(t) and v(t) values and write them in Table 1:

TABLE 1	t_0	t_A	t_f
t			
s(t)			
v(t)			

Calculate the quantities (write the measure units):

$\langle v\rangle_{fo} = (s(t_f) - s(t_o)) / (t_f - t_o)$ =…………………………………

arithmetic mean $\langle v\rangle = (v(t_0) + v(t_1) + v(t_f))/3$=………………………….
and comment differences/similarities

B3) Write in Table 2 :
first row : the time values of table 1,
second row: the values obtained from the equation: $\mathbf{s_{model1}(t) = s(t_o) + \langle v\rangle \times (t - t_o)}$,
third row: the values obtained from the equation: $\mathbf{s_{model2}(t) = s(t_o) + \langle v\rangle_{f0} \times (t - t_o)}$.
fourth row: the values of s(t) of table 1

TABLE 2	t_0	t_A	t_{stop1}
t			
$s_{model1}(t)$			
$s_{model2}(t)$			
s (t)			

Compare the values of second, third and fourth rows and comment carefully.

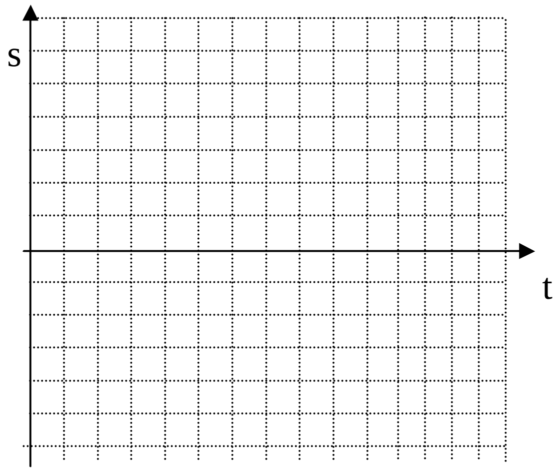
What is the most significant scientific content you have learned today in this activity?

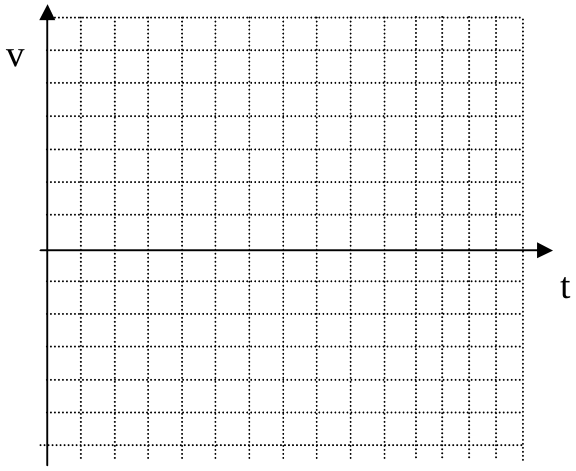
What physics/mathematics question is uppermost in your mind as you leave this activity?

Students' worksheet #9: Cart motion versus student's walk: s(t) and v(t)

The experiment is the measure of the motion of a cart on a horizontal track and of a regular walk of a student, between the same measured positions s_o and s_f. The cart is given a sudden kick. moves away and is stopped suddenly at s_f. Aftewards a student walks regularly away in between s_o and s_f

A) ***Sonar on.*** *Measure the motion of the cart.* Observe the displayed s(t) and v(t), draw them in the following graphs, using appropriate measure units and scales on axis. Save the experiment for comparison with the student's walks.





A1) ***Sonar on.*** *The measure for the motion of the student t is done between the same positions* . Observe the measured s(t) and v(t) and draw them with a different colour pen in the above graphs,

Comment the different features of the two s(t) and of the two v(t) graphs and explain .

s(t) --

----

v(t) --

A2) Comment the similar features of the two s(t) and of the two v(t) graphs and explain.

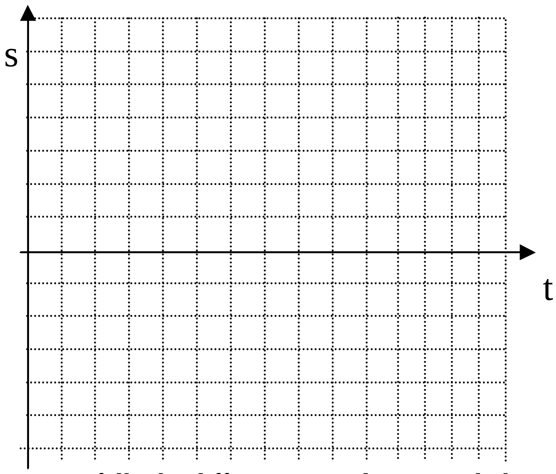
s(t)--

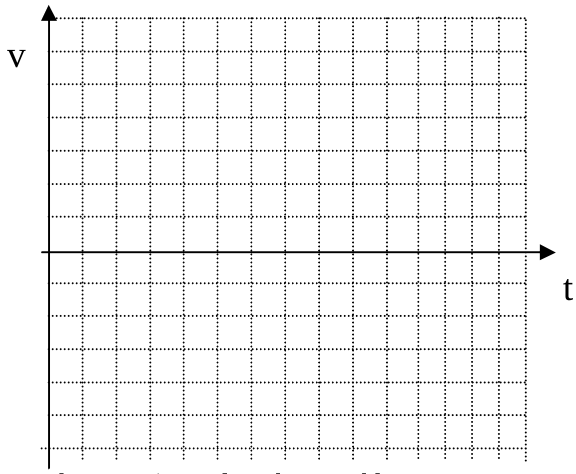
----

v(t) --

A3) Is the velocity of the cart, after the kick and before the stop, constant? ? If YES, write its value and explain on what data you base your answer. If NO, explain on what data you base your answer; explain if it is possible (and how) to find a almost constant average value for it. Comment carefully.

B1) **Sonar on**. *Repeat the experiment with the cart , this time increase the friction on a part of the track.* Observe the measured s(t) and v(t) and draw them below.





Comment carefully the differences/similarities with the measures done in A). Explain the possible reasons.

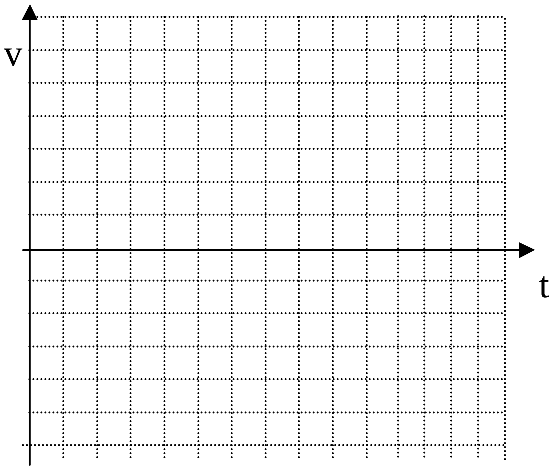
What is the most significant scientific content you have learned today in this activity?

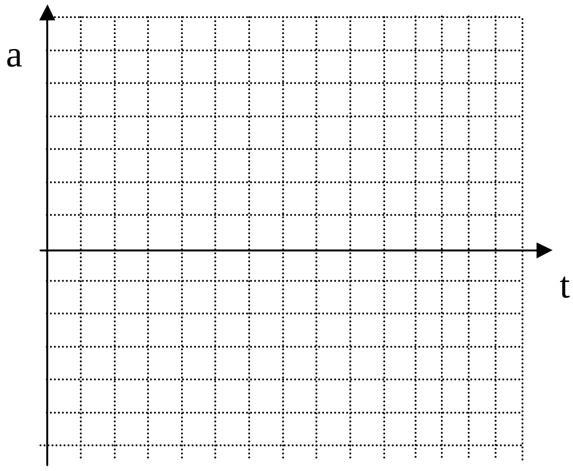
What physics/mathematics question is uppermost in your mind as you leave this activity?

Students' worksheet #10: Cart motion versus student's regular walk: v(t) and a(t)

The experiment is the measure of the motion of a cart on a horizontal track and of a regular walk of a student, between the same measured positions s_o and s_f. The cart is given a sudden kick. moves away and is stopped suddenly at s_f. After a student walks regularly away in between s_o and s_f

A) ***Sonar on(two graph display, v(t and a(t)).*** *Measure the motion of the cart.* Observe the displayed v(t) and a(t), draw them in the following graphs, using appropriate measure units and scales on axis. Save the experiment for comparison with the student's walks.





A1) Describe, in words, the measured for v(t) and a(t) graphs and comment carefully

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A1) ***Sonar on.*** *The measure for the motion of the student is done between the same positions* . Observe the measured a(t) and v(t) and draw them with a different colour pen in the above graphs,

Comment the different features of the two a(t) graphs and suggest the reasons for these differences.

A2) Comment the similar features of the two a (t) graphs and suggest the reasons for these similarities.

s(t)---

----

v(t) ---

A3) Is the acceleration of the cart, after the kick and before the stop, constant? If YES, write its value and explain on what data you base your answer. If NO, explain on what data you base your answer and explain if it is possible (and how) to find a average almost constant value for it. Comment carefully.

What is the most significant scientific content you have learned today in this activity?

What physics/mathematics question is uppermost in your mind as you leave this activity?

Another path: Galilean Composition of Velocity

A possible Script

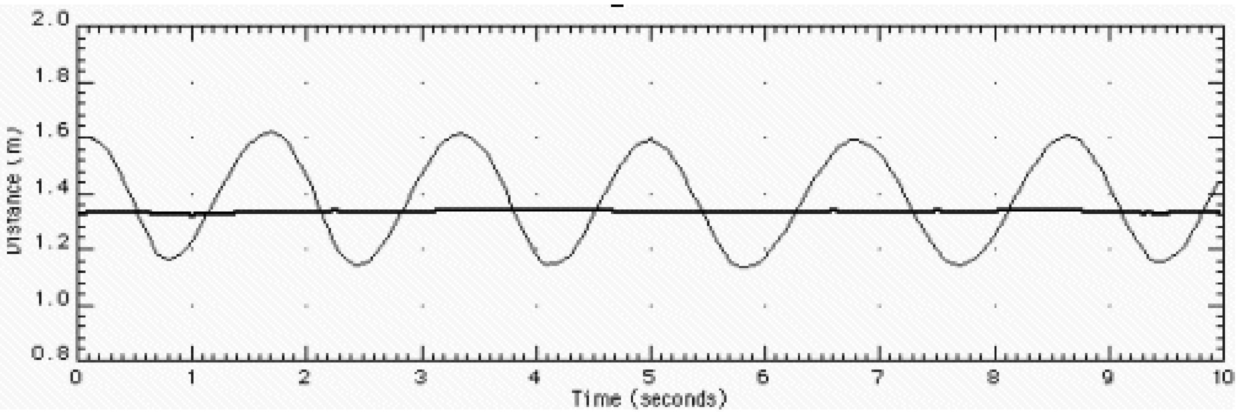
COMP-1 An object is moved back/forth by a still person: analysis via graphs s(t) and v(t).

a) the student stands still in front of the motion sensor, keeping in front of his/her chest, a rather rigid object (a pie dish, a book, …). Using a one graph display (s(t)), the position of the plate is measured and saved with an evocative name

b) Sensor Off: the still student moves the plate back/forth by moving rhythmically the arms. This motion is repeated several times until the student, perceptually, finds a good rhythm. The class is asked to observe carefully the motion of the plate

c) The students predict the position vs. time graph of the plate, in words and with a sketch. Ideas and reasoning emerged in the discussion are noted on an informal poster. Elicit ideas about Coordinate Systems, why they are used, their meaning, and the System used in their sketches

d) Sensor On, use a 2 s(t) graphs display showing the saved still plate. Move the plate and measure. Typical data are shown in the following figure

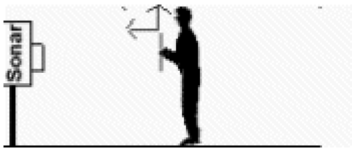


s(t) of still plate (black) and of plate moved by a still person (grey)

Comparison with students' predictions in the spirit of the learning cycle PEC (Prediction-Experiment –Comparison). If needed repeat more than once and clarify the role of the Coordinate System.

e) Encourage the students to discuss the "quasi oscillatory" and “quasi periodic” trend of s(t) of the plate around its equilibrium position. Ask for an estimation of the quasi-period. Discuss the s(t) in relation with the sequel of going toward - away from the sensor in the motion of the plate.

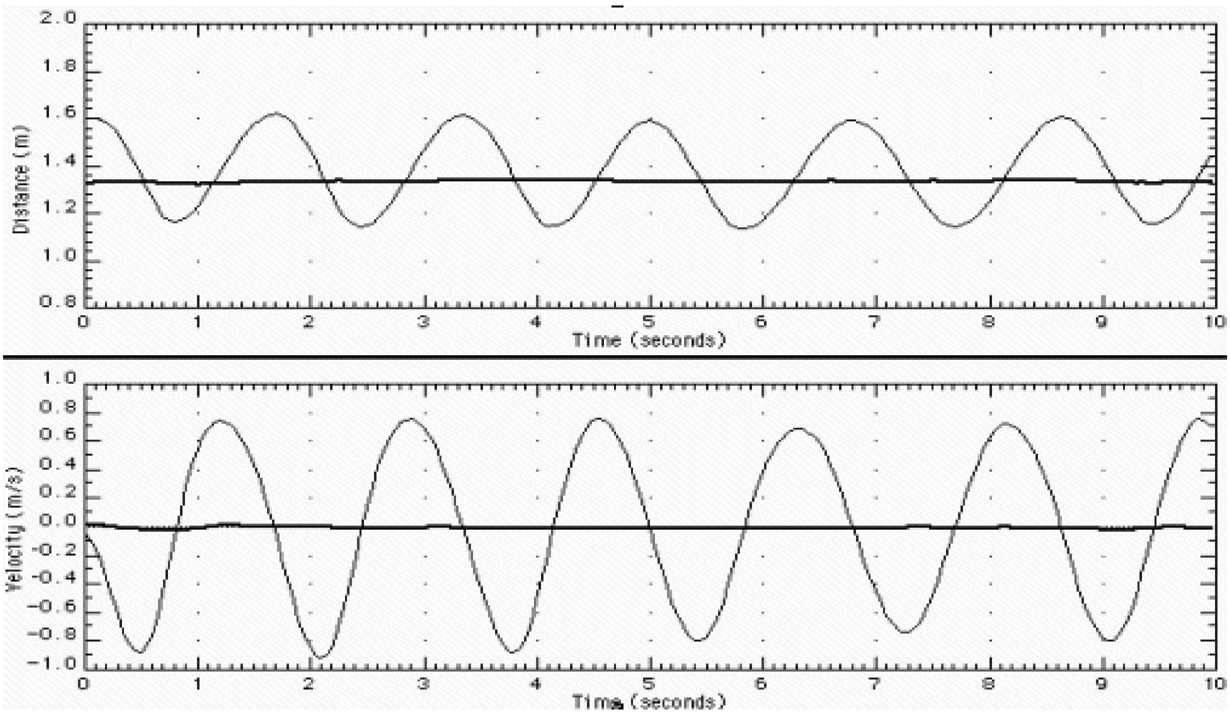
f) Address possible difficulties about Coordinate System used in the software (usually the sensor is the origin and the positive x axis goes away from it, increasing distances). Help the students to become aware that, when the person stands still, her/his Coordinate System can be taken coincident with the sensor one, and that only direction of x axis has to be chosen (cf. schema). Discuss relationships amongst different Coordinate Systems



g) To conclude the Coordinate System issue, ask the students to predict, in words and with sketches, the s(t) trend of the moved plate in the System of the still person. Help them to understand that the trend is the same but that there could be an exchange s(t) -> -s(t): when the plate is moving away from the sensor System (that may differ from the Lab one for a shift in the Origin position) this motion may be a motin toward the person

h) Going back to the s(t) measured by the Sensor, have its graph again observed carefully and to predict, according to its features, the trend of the corresponding v(t) graph. Ask for predictions in words and with sketches. Ideas and reasoning emerged in the discussion are noted on an informal poster.

i) With a 2 graphs display analyse the s(t) and v(t) trends and ask to compare the measured v(t) with the above predictions. Typical data are shown in the following figure). If needed iterate the PEC cycle. Help to clarify that the variations in v(t) are more evident than those in s(t) because of the finite different method used to calculate the velocity values



s(t), v(t) of a still plate (in black) and of the plate moved by a still person (in grey)

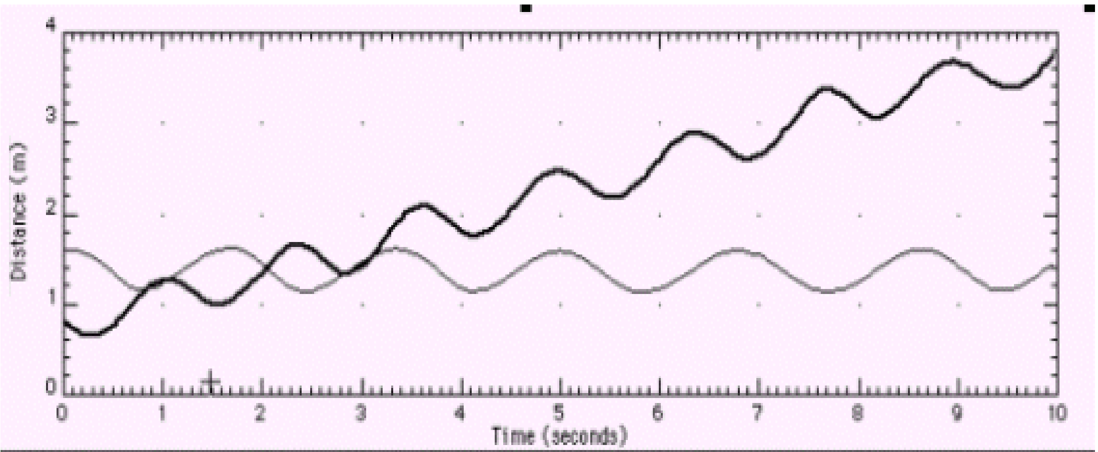
j) Ask to correlate the v(t) trend with the s(t) one, focusing on their “periodicity” and on how the inversions in the motion are represented and correlated in the graph

COMP-2 An object is moved back/forth by a person walking regularly away from and toward the motion sensor: analysis via graphs s(t) and v(t).

a) Sensor Off: the student walks regularly away from the sensor while moving the plate back/forth rhythmically with the arms, as in Comp-1. The class observe carefully the motion of the plate and predict the position vs. time graph of the plate, in words and with a sketch. Ideas and reasoning emerged in the discussion are noted. Elicit ideas about velocity of the plate

b) Sensor On: the student repeats the experiment and the measured s(t) graph is carefully observed. Keep track of key points from this discussion. Have the students compare data and predictions, practicing the PEC cycle. Focus should be on how and if the walking affect the motion of the plate

c) The students combine in one graph the above s(t) with that of the plate moved by a still person, saved in Comp-1. Typical data are shown in the following figure. Help to discuss similarities and differences between the two trends, calling attention on their "quasi periodicity". Ask to explain why the trend of the s(t) of the plate moved by the walking away student is globally increasing



s(t) of plate moved by a still student (in grey) and by student walking regularly away from sensor (in black).

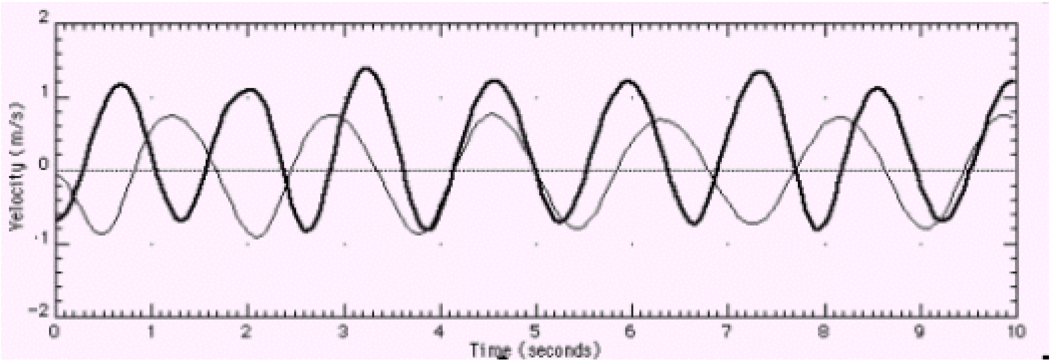
d) Focus on the very fact that the sensor measures the position of the plate, moved by the arms and "dragged" by he walking. Start the formalization by distinguishing:
- position of plate moved by the still student (s' plate, Coordinate Sistem of the student);
- position of the walking student (speople, Coordinate System of the Laboratory);
- position of plate moved by the walking student (splate , Coordinate System of the Laboratory).

e) Ask the class to reflect on the features of the s(t) of the plate moved by the walking student and predict the trend of the corresponding v(t), in words and with sketches.

f) Use a 2 graph display to observe s(t) and v(t) together. Compare experimental v(t) with the above predictions. If needed iterate the PEC cycle.

g) Have the students combine in a graph the 2 s(t) of the plate using the one saved in Comp-1. Typical data are shown in the following figure. Similarities and differences are discussed, focus on the "quasi periodic" structure of both trends is helpful. Ask for hypothesis explaining the "higher" (on average) value of the velocity of the plate moved by the walking student Continue the formalization distinguishing, as for the position:

- velocity of plate moved by still student (v'plate); - velocity of walking student (vpeople); - velocity of plate moved by walking student (vplate).

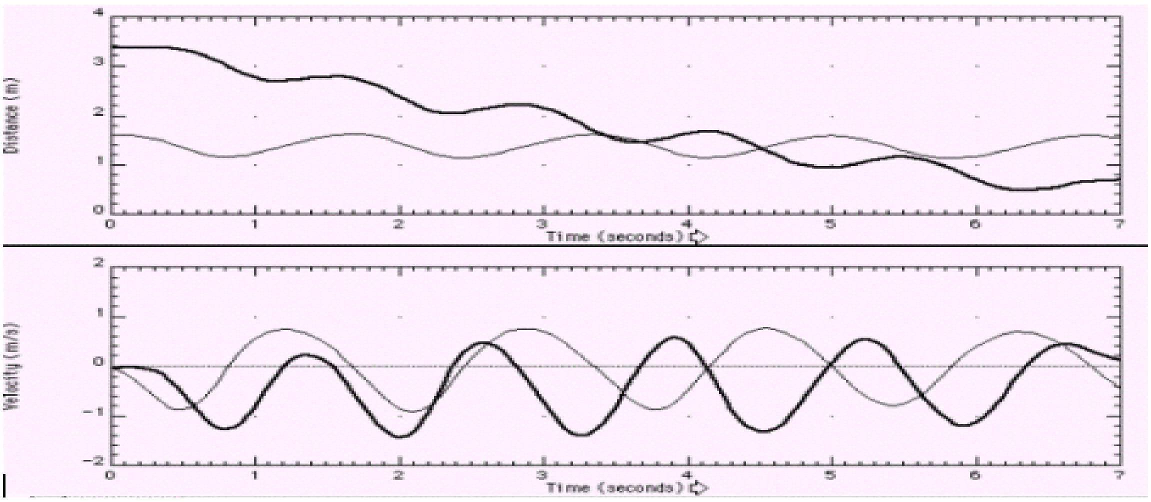


v(t) of a plate moved by a still student (in grey) and by a student walking regularly away from sensor (in black).

h) Discuss if and how vplate can be obtained from v'plate and vpeople. Keep track of ideas and reasoning patterns. Ask for everyday experience of velocity combination, e.g. car overtaking on freeway, position of umbrella when still or walking in the rain, …)

i) Help noting that when walking away from the sensor the velocity of the walking suns up the plate velocity. The students estimate from the v(t) graph the v of the walking and compare this value with the average value of the "up translation " of the v of the plate moved by the walking student

j) Ask predictions of s(t) and v(t) trends when the plate is moved by a person walking regularly toward the sensor. Have a student perform the experiment. The class observes the data in a 2 graphs display in order to see also the s(t) and v(t) saved in Comp-1 (cf. figure).



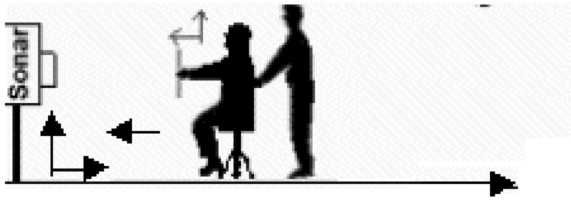
s(t), v(t) plate moved by a still person (grey) and by a student walking toward the sensor (black).

k) The students compare s(t) and v(t) in the cases of walking away and toward the sensor. Help to become aware that when walking away (toward) at any time, the about constant positive (negative) velocity of the walking adds up to that of the plate.

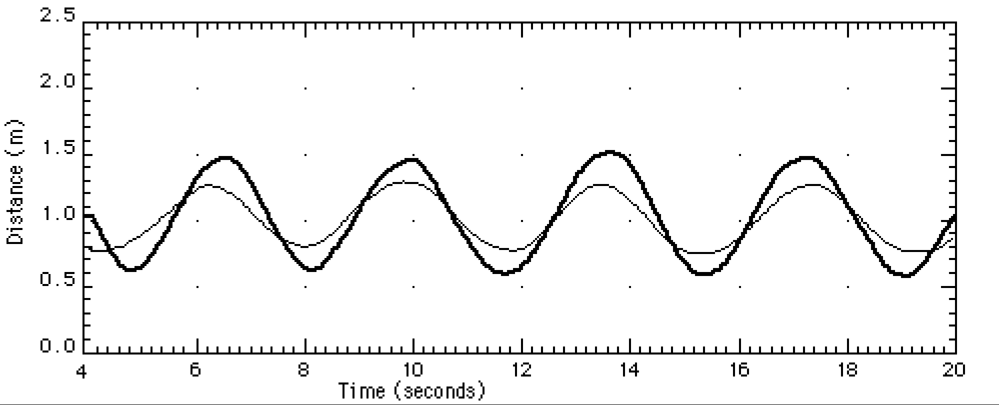
l) Help to abstract to the rule "velocity of plate when the person is walking is equal to the sum or difference of the velocity of the plate moved by a still person and the velocity of the walking"

COMP-3 An object is moved back/forth by a person on a chair moved back/forth (in phase with the plate): analysis via graphs s(t) and v(t).

a) Sensor Off: a student moves the plate back/forth while seated on a chair (ex. a wheeled office one) first when the chair is still, then when it is moved back/forth by another student, in phase with the plate. (Cf. schema). The experiment is repeated until the two student find a synchronous rhythm. The class observe carefully the two motions and predict the s(t) of both plate and chair.



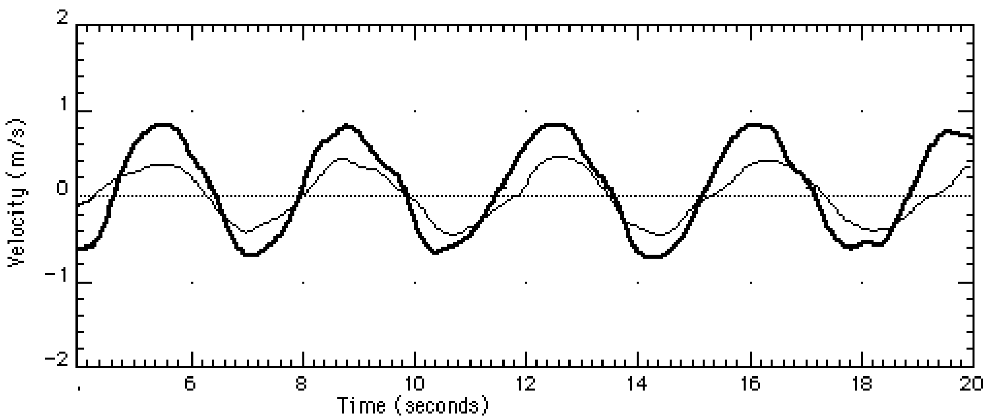
b) Sensor On and 1 graph display: the student moves the plate while the chair is still and when it is moved in phase. (Typical data in the figure). Discuss similarities and difficulties, focus on the "quasi periodic" trends. Ask for hypotheses to explain why the average amplitude of s(t) is greater when the chair is moved in phase with the plate



s(t) of plate moved by student on still chair (grey) and on chair moved in phase with the plate (black)

c) Ask for predictions of v(t) on the basis of the features of the plate s(t) when the chair motion is "in phase", both in words and with a sketch. Note ideas and reasoning patterns emerged in the predictions.

d) The students display the v(t) graphs (typical results in the figure) and compare their predictions with the experimental trends. If needed iterate the PEC cycle. Have the class discuss differences and similarities and explain the main features of the two trends.



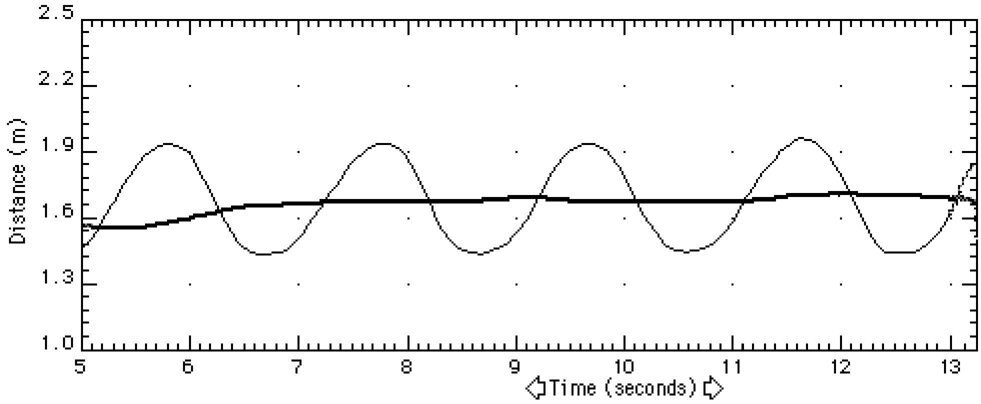
v(t) of plate moved by student on still chair (grey) and on chair moved in phase with the plate (black)

e) Recall the conclusions of COMP-2. Help the class become aware that also in this case the velocity of the chair sum up to that of the plate. By abstraction guide to a rule similar to the one found in COMP-2: " the velocity of the plate when the person is seated on a chair moved in phase with the plate is equal to the sum of the velocity of the plate when the chair is still and the velocity of the chair when it is moved"

COMP-4 An object is moved back/forth by a person on a chair moved back/forth (in counter-phase with the plate): analysis via graphs s(t) and v(t).

a) Sensor Off: a student moves the plate back/forth while seated on a chair (ex. a wheeled office one) first when the chair is still, then when it is moved back/forth by another student, in counter-phase with the plate. The experiment is repeated until a good synchronous rhythm is found. The class observe carefully the two motions and predict the s(t) of both plate and chair.

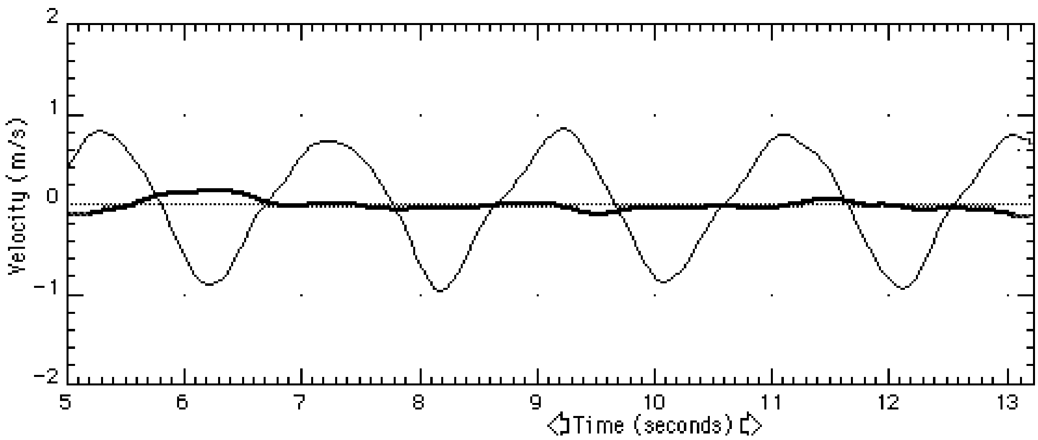
b) Sensor On and 1 graph display: the student moves the plate while the chair is still and when it is moved. (Typical data in the figure). Discuss similarities and difficulties, focusing on the "quasi periodic" trends. Ask for hypotheses to explain why the average amplitude of s(t) is about zero when the chair is moved in counter-phase with the plate



s(t) of plate moved by student on still chair (grey) and on chair moved in counter-phase with the plate (black)

c) The class predicts the v(t) trends on the basis of features of the plate s(t) when the chair motion is "in counter-phase", both in words and in sketch. The emerged ideas and reasoning patterns are noted on an informal poster. Ask the students how a quasi zero velocity can result by combining two different motions

d) The students display the v(t) graphs (typical results in the figure) and compare their predictions with the experimental trends. If needed iterate the PEC cycle. Have the class discuss differences and similarities and explain the main features of the two v(t) trends.



v(t) of plate moved by student on still chair (grey) and on chair moved in counter-phase with the plate (black)

e) Ask the students to discuss the structure of both v(t), focusing on explaining why the velocity of the plate, when the chair is moved in counter-phase, is on average zero

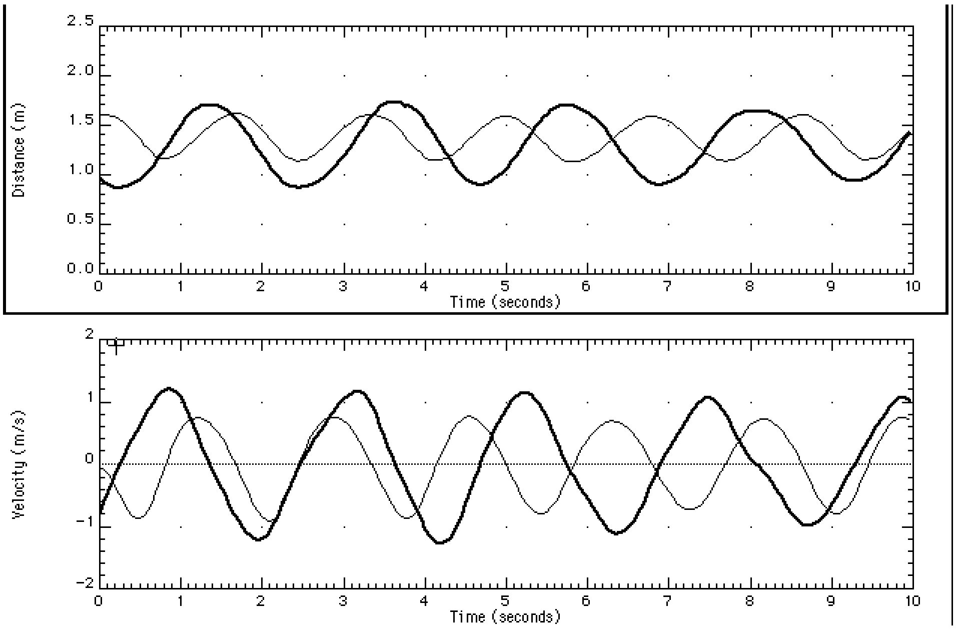
f) Recall the conclusions of COMP-3. Have the students discuss the differences with respect to the case of the chair moved in phase with the plate. Help the class become aware that also in this case the velocity of the chair sums up to that of the plate: therefore if the rhythm is a good one, the plate is almost still. Guide the students to identify a rule similar to the one previously found: "the velocity of the plate when the person is seated on a chair moved in counter-phase with the plate is equal to the sum of the velocity of the plate when the chair is still and the velocity of the chair when it is moved"

COMP-5 An object is moved back/forth by a student oscillating rhythmically on still feet: analysis via graphs s(t) and v(t).

a) Sensor Off: a student moves the plate back/forth while s/he moves rhythmically back/forth keeping the feet still on the floor (kind of an oscillation of the body), in phase with the plate motion (i.e., the trunk is toward the sensor when the plate moves toward and viceversa). The experiment is repeated until the student feels that a good rhythm is found. The class observe carefully the experiment and predict, in words and by sketches, the s(t) of both plate and body of the student. The key ideas and reasoning patterns emerged in this “prediction phase” are noted in an informal poster

b) Sensor On and 2 graphs display (s(t) and v(t)): the experiment is repeated and the class observe carefully the collected data. Have the students discuss similarities and difficulties of the 2 graphs, focusing on the "quasi periodic" trends and compare the experimental trends with the above predictions. Have the class discuss differences and similarities and explain the main features of the two v(t) trends. If needed iterate the PEC cycle.

c) The students build a graph displaying s(t) and v(t) graphs of plate moved by a still person (saved in COMP-1) and the above experiment. (typical results in the figure). Have the class discuss similarities and differences.



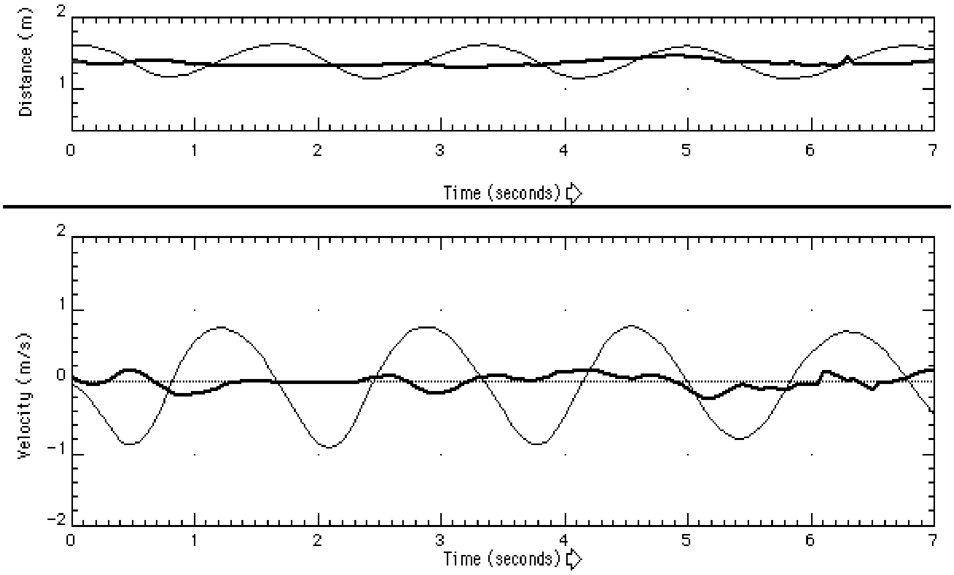
s(t) and v(t) of plate moved by a student still (grey) or oscillating rhythmically in phase (black)

d) Ask the students to compare the results of this experiment with those obtained when the plate was moved by a student on a chair moved in phase with the plate and to comment differences and similarities of the two cases. Insist on explanation based on perceptual knowledge. Note and share ideas emerged in this discussion. Help the students become aware that also in the case of “quasi oscillatory” motion of the body, at any time, the velocity of the body adds up the velocity of the plate.

e) Sensor Off: the experiment is repeated but now the student “oscillates” in counter –phase with the plate (the trunk is toward the sensor when the plate moves away and viceversa). The class observe the motions and predict, in words and by sketches, the s(t) of both plate and body of the student. As before, the key ideas and reasoning patterns emerged in this “prediction phase” are noted in an informal poster

f) Sensor On and 2 graphs display (s(t) and v(t)), the experiment is repeated. Have the class discuss/explain the main features of the two graphs. The students compare their predictions with the experimental trends. If needed iterate the PEC cycle.

g) The students build a graph displaying s(t) and v(t) of two experiment: a) plate moved by a still person; b) plate moved by a person "oscillating" in counter-phase (cfr. figure).



s(t) and v(t) of plate moved by a student still (grey) or oscillating rhythmically in counter-phase (black)

h) The students compare these results with those of the experiment when the person moving the plate was on a chair moved in counter-phase with the plate. (cfr. COMP-4). Have them discuss differences and similarities of the two situations. Help the class become aware that also in this case the velocity of the body adds up to that of the plate and identify a rule similar to the ones previously found: " at any instant, the velocity of the plate when the person "oscillates" in counter-phase with the plate is equal to the sum of the velocity of the plate when the person is still and the velocity of the body when it moves"

COMP VEL 6 Modelling the Galilean composition of velocities in 1D case

a) The students collect all the results from the previous activities on the composition of velocities. They discuss such results, focusing on the Coordinate Systems used (the one chosen by the software, the Laboratory one, and the one in solidarity with the person moving the plate), their differences and features.

b) The class recalls all the rules identified:

- **Plate moved by a person still or walking regularly**

  Rule 1 → *velocity of plate when the person walks is equal to sum or difference of the velocity of plate when the person is still and the velocity of the walk*

- **Plate moved by a person on a chair moved in phase or counter-phase with the plate**

  Rule 2 → *velocity of plate when the person is on a chair is equal to sum or difference of the velocity of plate when the person is still and the velocity of the chair*

- **Plate moved by a person "oscillating" on still feet in phase or counter-phase with the plate**

  Rule 3 → *velocity of plate when the person "oscillates" is equal to sum or difference of the velocity of plate when the person is still and the velocity of the "oscillation"*

c) Help the class become aware that the velocity of the plate moved by a still person appears in all the identified rules; it is the velocity of the plate in the Coordinate System in solidarity with the person. Suggest to name it as v'

d) Call the students' attention on the nature of the velocity that in all found rules combines with the velocity of the plate moved by a still person. Help the class to under stand that this term depends on the type of motion of the person moving the plate: - regular walk away or toward the sensor; - motion of the chair on which the person is seated in phase or counter-phase with the plate; - "oscillation" on still feet of the person.

e) Have the students discuss the meaning of the velocity of the person moving the plate, zero when s/he is still, positive or negative when s/he moves. This velocity is the one of the Coordinate System in solidarity with the person with respect to the Laboratory Coordinate System. Suggest to name it as v_r (sign included)

f) Recall the students' attention on the velocity of the plate measured by the sensor: this data is the velocity of the plate in the Laboratory Coordinate System and is affected by the motion of the person moving the plate. Suggest to name it as v .

g) In order to formalise the found rules in mathematical language, for the studied 1D case, help the class to become aware that a correct expression for the velocities' composition is:

$$v = v' + v_r$$

h) Ask the students what would be useful when the general 3D case is studied. Note their ideas and reasoning patterns and keep track of both on an informal poster. Help them to recognise the opportunity, not necessity, for a vector formalism, in the studied 1D case, as a preparation for the 2D and 3D cases, where vectors are indispensable.

Students' Worksheets

Refer to: COMP 1, 2 ***"Galileian composition of velocities"***

Name……………………… Date……………

COMP 1 : **Plate moved back/forth by a student still**

Sensor Off: A student stands still in front of the sensor, s/he moves rhythmically the plate by extending and withdrawing the arms

1) Predict, with a sketch on the figure, the trend of the position of the moving plate

you have just observed. Indicate the units on the axes.

Briefly describe the reasoning underlying your predictions

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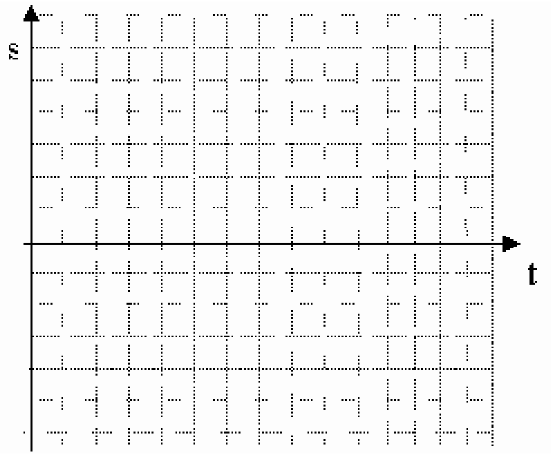

Sensor On

2) The plate motion is measured; observe carefully the experimental s(t). Sketch it in the above figure, in a different colour than the one used for your prediction. Briefly describe the main features of the s(t) trend. Compare with your prediction and comment differences and similarities.

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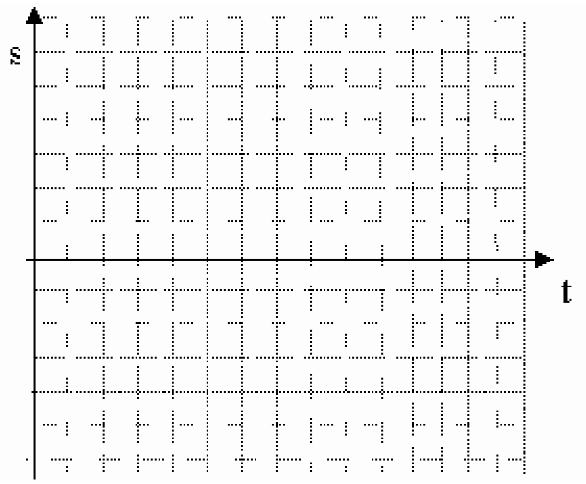
3) Predict, with a sketch on the figure, the trend of the position vs time of the moving plate in the case the sensor is on the chest of the person moving the plate. Indicate the units on the axes

Briefly describe the reasoning underlying your predictions ……………………………………………………



4) Compare your prediction with the s(t) measured in 2). Briefly describe the main differences between s(t) measured: **-** in the Coordinate System in solidarity with the sensor; **-** in the Coordinate System in solidarity with the person's chest.

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5) Write what you think may be a correct mathematical relation between the s(t) measured in the Laboratory Coordinate System and the one you predicted for the System in solidarity with the person's chest. Which role is played by the distance "person's chest – sensor" ?

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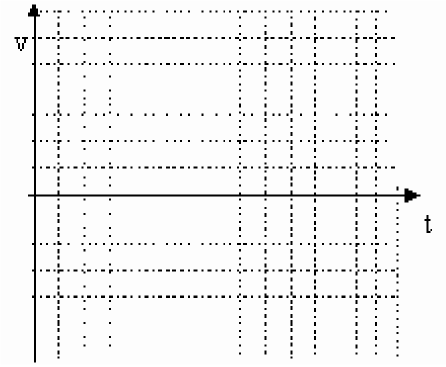
6) On the basis of the measured s(t), Predict, with a sketch on the figure, the trend of the velocity vs time of the moving plate (in the Laboratory Coordinate System).



Display the experimental v(t) graph

7) Compare the measured v(t) with your prediction. Discuss the main similarities and differences and explain

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8) On the previous figure, sketch in different colour, your prediction of the trend of v(t) in the Coordinate System in solidarity with the person's chest. According to you, which are the main differences and similarities with respect to the trend of the measured v(t)?

9) Write what you think may be a correct mathematical relation between the v(t) measured in the Laboratory Coordinate System and the one you predicted for the System in solidarity with the person's chest. Which role is played by the distance "person's chest – sensor" ?

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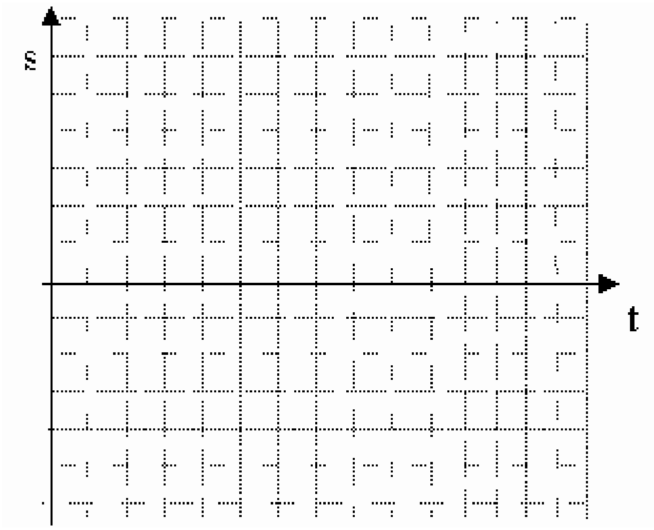
Refer to: COMP 2 ***"Galileian composition of velocities"***

Name……………………… Date……………

COMP 2: **Plate moved back/forth by a student walking regularly**

Sensor Off: a student walks regularly away from the sensor while moving the plate back/forth



1) Predict, with a sketch on the figure, the trend of the position vs time of the moving plate you have just observed. Use appropriate units on the axes. Briefly describe the reasoning underlying your predictions

……………………………………………………

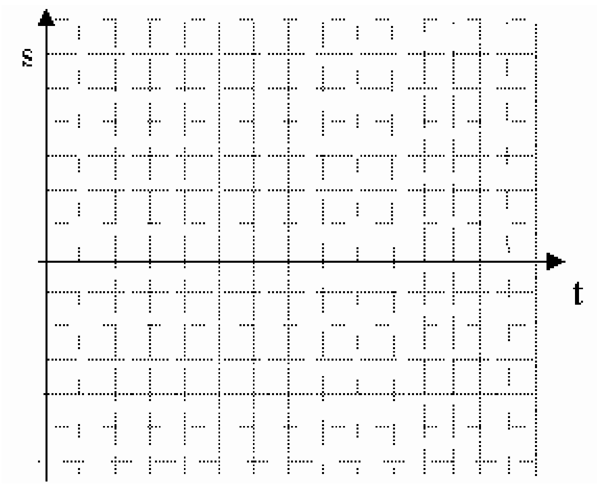
……………………………………………………

Sensor On, 1 graph display: the experiment is repeated and the motion measured .

2) Observe carefully the experimental s(t). Sketch it in the above figure, in a different colour than the one used for your prediction. Briefly describe the main features of the s(t) trend. Compare with your prediction and comment differences and similarities.

Using a 2 graphs display show together with the above s(t) also the s(t) of the plate moved by a still person.

3) Sketch, on the figure, the two above s(t) of the plate moved by the still person, possibly in different colours. Comment briefly the two trends and their similarities and differences



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4) Write what you think may be a correct mathematical relation between these two s(t)

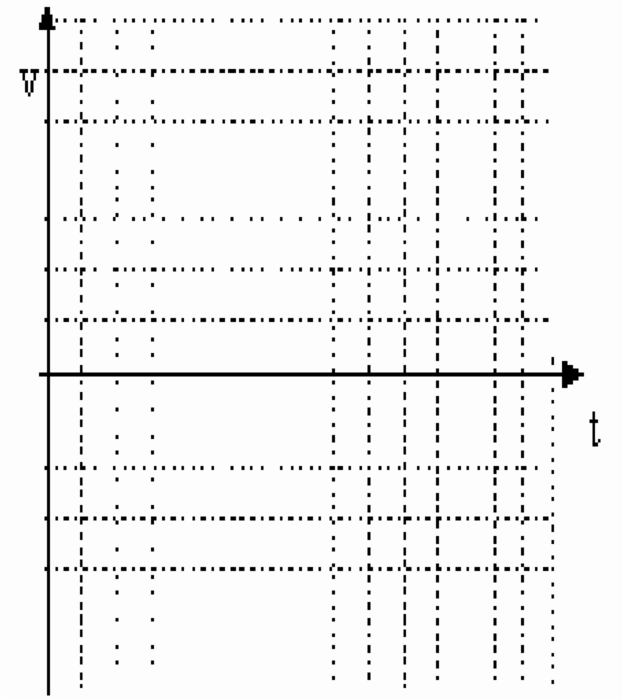
………

………

5) Estimate, from the experimental s(t) the average value of the velocity of the person walking away from the sensor

………. + - ………….

6) On the basis of the measured s(t), Predict, with a sketch on the figure, the trend of the velocity vs. time of the moving plate



Display the experimental v(t) graph

7) Sketch the experimental v(t) in the same figure, in a different colour. Compare the measured v(t) with your prediction. Discuss the main similarities and differences and explain

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8) Estimate from the experimental v(t) trend the average value of the velocity of the person walking away from the sensor

………. + - …………. compare with your previous estimation from s(t) and comment

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9) Write what you think may be a correct mathematical relation amongst the v(t) of the plate when the person moves away from the sensor, the v(t) of the plate when the person stands still and the velocity of the walking person. Explain.

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10)Write a similar relationships in the case of a person walking regularly toward the sensor. Discuss the differences with respect the previous situation

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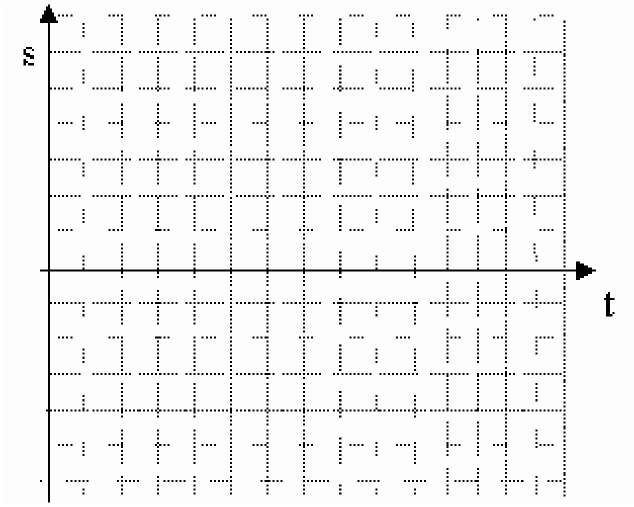
Refer to: COMP 3,4 ***"Galileian composition of velocities"***

Name……………………… Date……………

COMP 3,4: **Plate moved back/forth by a student on a chair moved back/forth**

Sensor Off: a student moves the plate while seated on a still chair

1) Predict, with a sketch on the figure, the trends of s(t) and v(t) of the moving plate you have just observed. Use appropriate units on the axes.



Briefly describe the reasoning underlying your predictions

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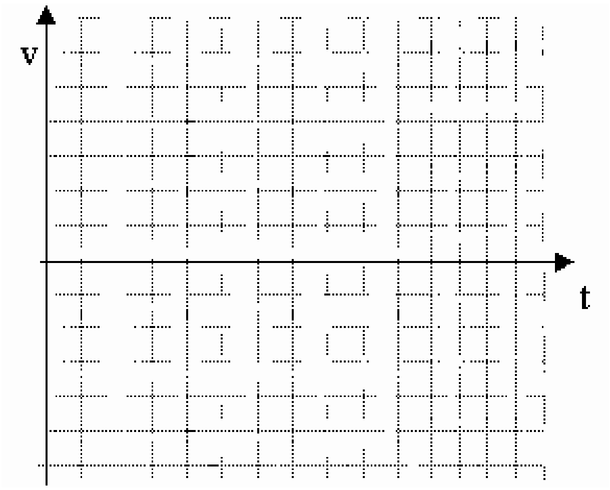

Sensor On and 2 graphs display (s(t) and v(t)): the experiment is repeated and the motion measured .

2) Observe carefully the experimental s(t) and v(t). Sketch them in the above figure, in colours different than the ones used for your prediction. Briefly describe the main features of the s(t) and v(t) trends. Compare with your prediction and explain differences and similarities.

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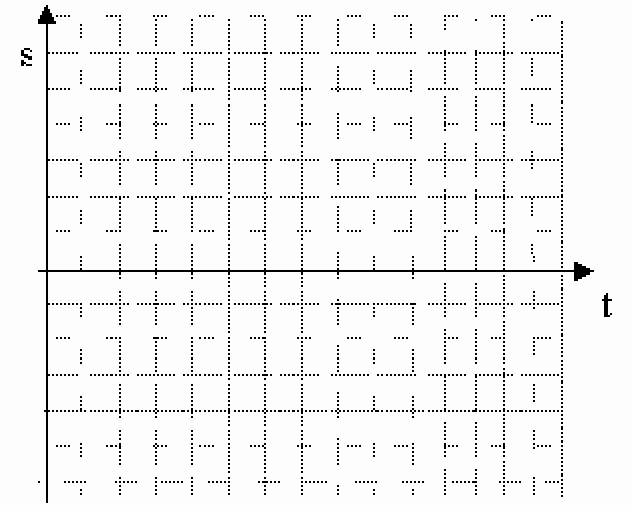
Sensor Off: a seated student moves the plate while the chair is moved back/forth, in phase with the plate, by a fellow student

1) Predict, with a sketch on the figure, the trends of s(t) and v(t) of the moving plate you have just observed. Use appropriate units on the axes.



Briefly describe the reasoning underlying your predictions

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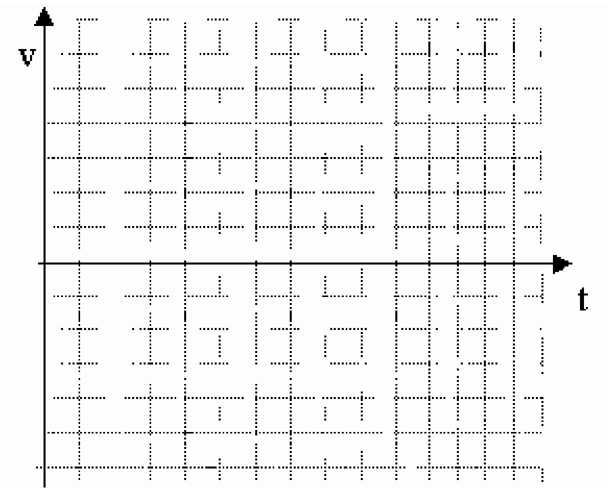

Sensor On, 2 graphs display: the experiment is repeated and the motion measured .

2) Observe carefully the experimental s(t) and v(t). Sketch them in the above figure, in colours than the ones used for your predictions. Briefly describe the main features of the s(t)and v(t) trend. Compare with your prediction, comment differences and similarities and explain

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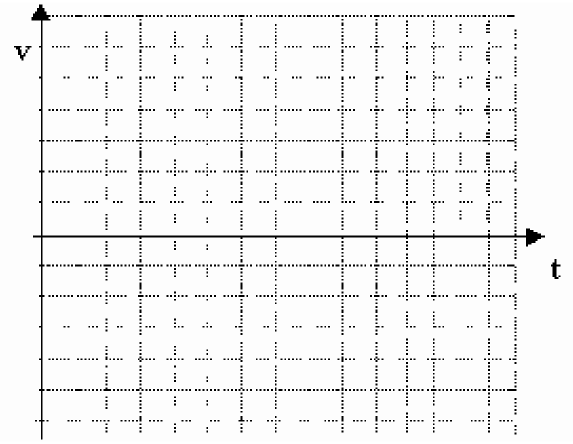
3) Sketch, on the figure, possibly in different colours, the v(t) of the plate when the chair is still and when it is moved. Comment briefly the two trends and their similarities and differences



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4) Write what you think may be a correct mathematical relationship allowing to get the plate velocity when the chair is moved from the one when the chair is still. Explain the meaning of all terms in the relationships
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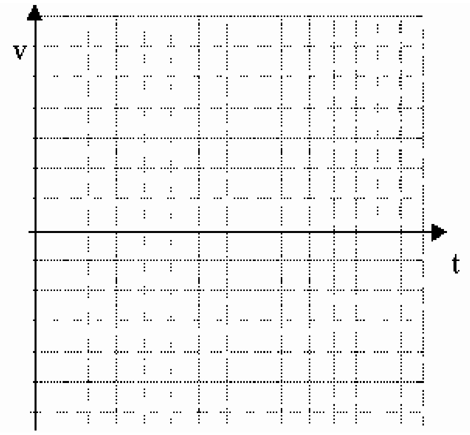
***Sensor Off:* a seated student moves the plate while the chair is moved back/forth, in counter- phase with the plate, by a fellow student**

5) Predict, with a sketch on the figure, the trend of v(t) of the moving plate you have just observed. Use appropriate units on the axes.



Briefly describe the reasoning underlying your predictions

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6) Write what you think may be a correct mathematical relationship allowing to get the plate velocity, when the chair is moved in counter-phase, from the one when the chair is still. Explain the meaning of all terms in the relationships
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Sensor On, 1 graph display (v(t)) The experiment is repeated: a seated student moves the plate while a fellow student moves the chair back/forth, in counter- phase with the plate

7) Observe carefully the experimental v(t). Sketch it in the above figure, in a different colour than the one used for your prediction. Briefly describe the main features of the s(t) trend. Compare with your prediction and comment differences and similarities.

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8) Write what you think it may be a correct mathematical relationship to get the v(t) of the plate when the chair is moved in counter-phase with the plate, from the v(t) of the plate when the chair stands. Explain.

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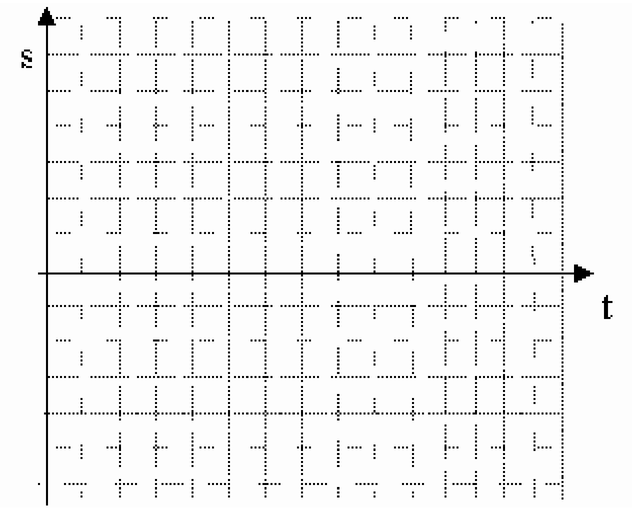
Refer to: COMP 5 ***"Galileian composition of velocities"***

Name……………………… Date……………

COMP 5: **Plate moved back/forth by a student who "oscillates" back/forth on still feet**

Sensor Off: a student moves the plate while "oscillating" back/forth on still feet, in phase with the plate

1) Predict, with a sketch on the figure, the trends of s(t) and v(t) of the moving plate you have just observed. Use appropriate units on the axes.



Briefly describe the reasoning underlying your predictions

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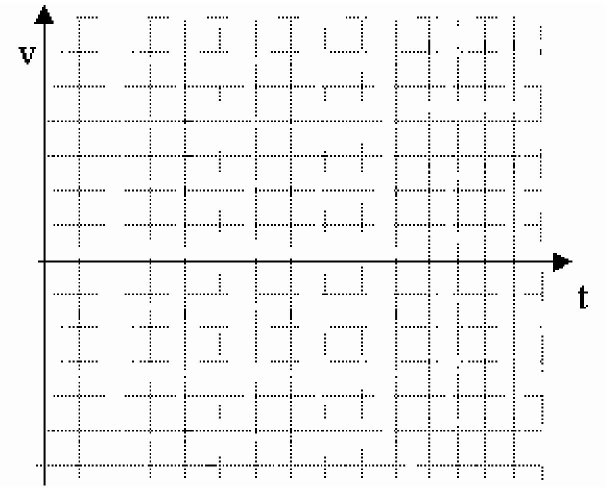

Sensor On and 2 graphs display (s(t) and v(t)): **the experiment is repeated and the motion measured .**

2) Observe carefully the experimental s(t) and v(t). Sketch them in the above figure, in colours different than the ones used for your prediction. Briefly describe the main features of the s(t) and v(t) trends. Compare with your prediction and explain differences and similarities.

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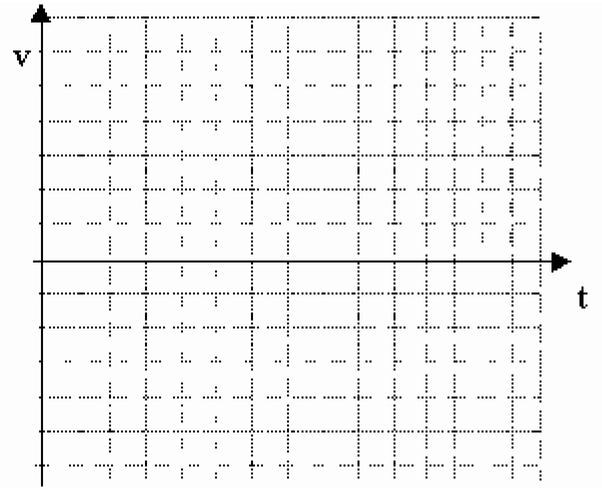
3) Sketch on the figure, the v(t) trend of the "oscillating" person in the hypothesis that the sensor measures the motion looking to the back of the person



4) Sketch on the figure, in a different colour, the v(t) trend of the "oscillating" person in the hypothesis that the sensor is put on the chest of the person

5) Write what you think may be a correct mathematical relationship connecting the plate velocity whit both the velocity of the person "oscillating" in phase with the plate and the velocity of the plate in the case the sensor is on the chest of the person.. Explain the meaning of all terms in the relationships

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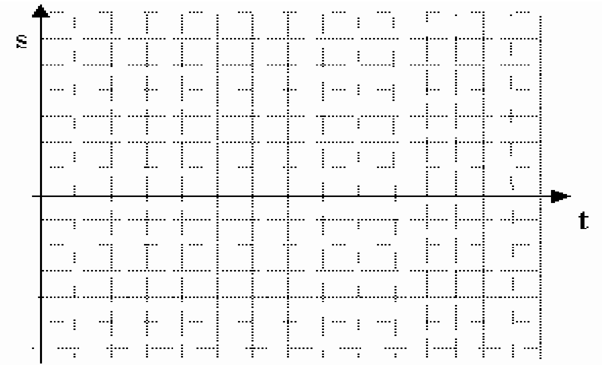
Sensor Off: a student moves the plate while "oscillating" back/forth on still feet, in counter-phase with the plate

6) Predict, with a sketch on the figure, the trends of s(t) and v(t) of the moving plate you have just observed. Use appropriate units on the axes.



Briefly describe the reasoning underlying your predictions

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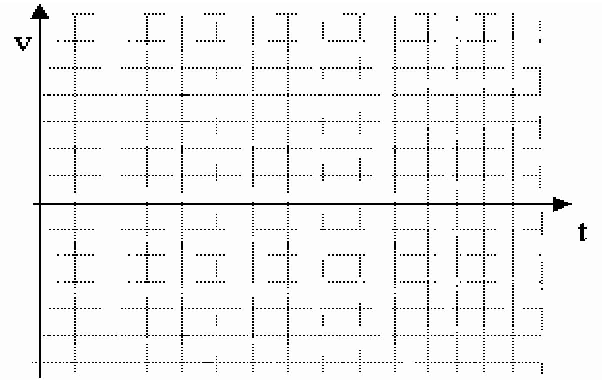

Sensor On and 2 graphs display (s(t) and v(t)): **the experiment is repeated and the motion measured**

7) Observe carefully the experimental s(t) and v(t). Sketch them in the above figure, in colours different than the ones used for your predictions. Briefly describe the main features of the s(t) and v(t) trends. Compare with your prediction and explain differences and similarities.

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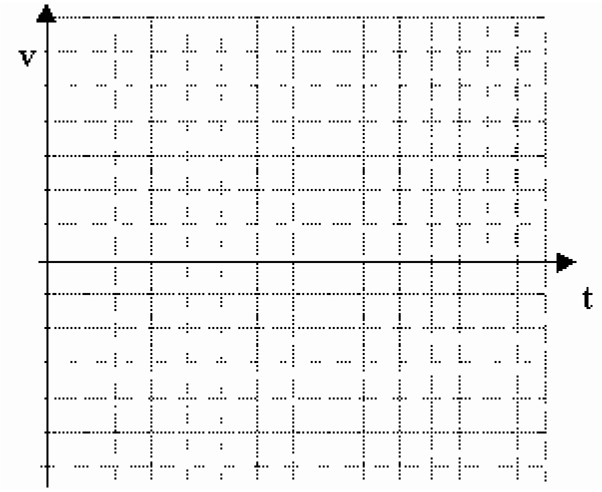
8) Predict, with a sketch on the figure, the trend of v(t) of the person "oscillating" in counter-phase with the plate, in the case of a sensor that "sees" of the person from his/her back. Use appropriate units on the axes.

9) Predict, with a sketch on the figure, in another colour, the trend of v(t) of the person "oscillating" in counter-phase with the plate, in the case of a sensor located on the chest of the person.



8) Write what you think it may be a correct mathematical relationship connecting the v(t) of the plate with the velocity of the person "oscillating" in counter-phase with the plate, in the case of the sensor located on the chest of the person. Explain the meaning of all terms in the relationship

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Another path: Inversions of motion

A possible script

INVFI 1
Experiments on a regular walk, with a inversion: analysis of s(t) and v(t) graphs

(a) Choose a one graph display (s(t)) and have a student walk in front of the sensor. Check that the movement is clearly seen by the sensor and that the graph s(t) is easily readable
.

(b) Sensor Off: student walks regularly away / towards the sensor making a quick inversion of motion. Ask the class to predict, in words and with a sketch, how could the inversion be represented in the s(t) graph. Share and note the keywords used in the discussion.

(c) Sensor On: the walk is repeated as close as possible to the previous one. Have the students optimize the readability of the s(t) graph and save the experiment with an evocative file name. Discuss how it a walk away, an inversion and a walk towards the sensor is represented in a s(t) graph. Ask the students estimate the duration of the motion by readings the graph.

(d) Ask the students to predict, in words and with a sketch, the pattern of the corresponding v(t) graph, with particular attention to the iconic representation of the motion inversion. The class compares predictions with experimental results and, if needed, the PEC cycle is iterated.

(e) The class exchange ideas about the inversion as it is shown in the v(t) graph (it is quite common a confusion between v(t) and s(t)). Share and record key issues
.

(f) Using a two graphs display, s(t) and v(t), vertically aligned, have students discuss their relationships with particular attention to the zero value of the velocity at the inversion.

INVFI 2
Experiments with various inversions; analysis of s(t), v(t) and a(t) graphs

(a) Recall the s(t) saved from the previous session. A student walks in a similar way but with an inversion as quick as possible. The “best” experimental results are saved .

(b) The students optimize the readability of the image and discuss the comparison of the two inversions as they appear in the s(t) graph

(c) Ask to predict, in words and with a sketch, the corresponding trend of v (t), with particular attention to the motion inversion. Share and note ideas and reasoning patterns

(d) The v(t) graph is shown in a two graphs display (s (t), v(t)). Compare the predictions with experimental results and, if needed, iterate the PEC cycle.

(e) The students estimate from the v(t) graph the duration of the inversion of motion and compare it with a perceptual estimation.

(f) The students discuss the graph part around zero in v(t) in comparison with an ideal mathematical sharp step function and suggest justification for the differences

(g) The class experiments with different inversions, the most rapid ones, and analyses the changes in the graph region around zero in v(t). Help students to reflect about the influence of the reflexes time of a person making a motion inversion and to discuss which forces are at play when the motion reverses. Record and share these ideas.

(h) In a three graphs display, s(t), v(t) and a(t), the students analyze the changes in the acceleration, around the inversion of motion and if and how they are affected by the duration of the inversion. Help them become aware of the fact that in a real phenomenon, the variation of speed can never be instantaneous. Discuss how an instantaneous change in any motion would lead to an ideal step in v(t) and hence to an infinite acceleration, which is not possible in the case of a real system.

INVFI 3
Experiments with a cart inverting its motion on a horizontal guide: analysis of s(t) and v(t) graphs

(a) Sensor off: the students observe the motion of a cart, kicked by a small push, which goes away from the sensor, hits against the bumper of an horizontal smooth guide and then goes back, taking care to stop it before hitting the sensor, to avoid artefacts in the measure. Ask to predict the s(t) graphs. Share and note key features of these predictions.

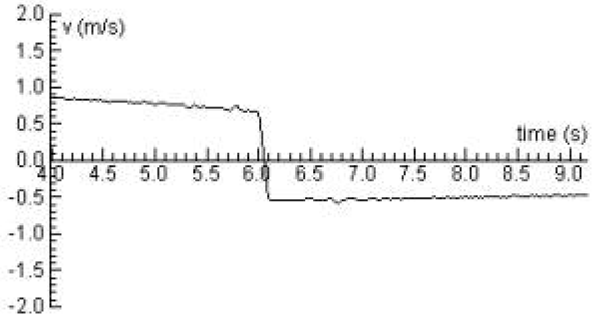
(b) Sensor on and a one graph display (s(t)): the students: repeat the experiment and optimize the readability of the image; load one of the previous experiments with a regular walking featuring a quick inversion; build a two graph display with both the s(t) graphs and comment on similarities and differences.

(c) From the s(t) of the cart the class estimates the duration of the inversion of motion and the time at which it occurs. The students predict the trend of the v(t) graph with particular attention to the iconic representation. Share and record the emerged ideas.

(d) The students display the v(t) of the cart, improving the image readability and compare with predictions. If needed, iterate the PEC cycle and clarify.

(e) The students load the v(t) graph of the walk with inversion investigated in b); construct an image of two v(t) graphs vertically aligned; comment on similarities and differences. Point out the greater regularity of the cart v(t) which does not present the modulation of steps characteristic of a walking.

(f) The class discusses the slope of the step in v(t) around the zero (typical data in figure below) and compares with that of the walk.

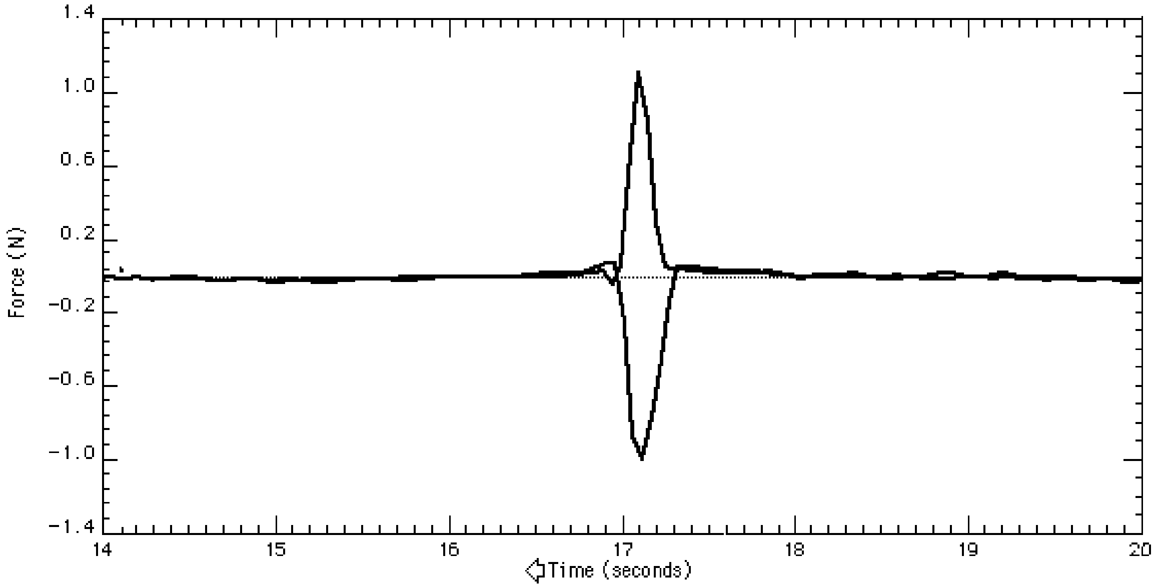


(g) Students estimate from the v(t) of the cart the time of the inversion and the values of speed immediately before and after the collision, aiming at an order relationship between them.

(h) Students discuss about forces involved in the hit between the cart and the bumper. Pay attention to to possible reasoning patterns as “the cart has more force than the bumper because of its greater weight”. Propose to discuss the impact in terms of energy, for example by using analogies with collisions between cars and consequent damages. Record and share main typical ideas

(i) Introduce the concept of impulsive force and characterize the interaction (collision) bumper-cart with it. Have the class discuss ideas on various physical effects (deformation, heat, sound, etc.) involved in the impact.

(j) Explain how an experiment of a collision between two carts can be performed on using two force sensors and clarify the meaning of two contemporary and independent measures. Show a F(t) graph of such an experiment (see Figure below) and ask to estimate the duration of the impulsive forces at play, call attention on the fact that they are equal and opposite. Make a connection with a possible subsequent more detailed discussion about the third law of dynamics.



INVFI4.

Experiments with a cart going up/own (more than once) a smooth ramp: analysis of s(t), v(t) and a(t) graphs

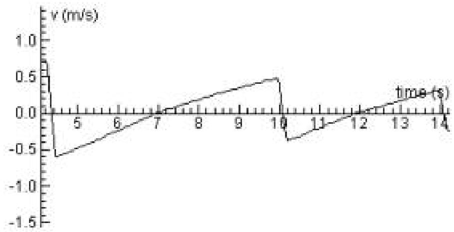
(a) Sensor Off A student does the experiment: a cart on top of an incline starts from rest, goes, hits a bumper and goes up and so on until it stops at the bottom of the ramp. Ask to predict with words and a sketch the trend of s(t), with particular attention to the inversion of motion. Share and record the main ideas emerged in the predictions.

(b) Sensor On: the experiment is repeated, using a one graph display (s (t)). Ask to explain the maxima and minima in s(t) and guide the students to relate them to the inversion of motion. Clarify that, if the sensor is on top of the ramp, the maxima correspond to the hits against the bumper, while the minima correspond to the inversions when the cart reaches the maximum height on the ramp.

(c) The class estimates, by readings s(t) graph, the duration of the inversions and the times of occurrence, and predict the trend of v(t) graph with particular attention to the inversions of motion.

(d) In a two graphs display (s(t), v(t)), students show v(t) and compare with their predictions; if needed, iterate the PEC cycle.

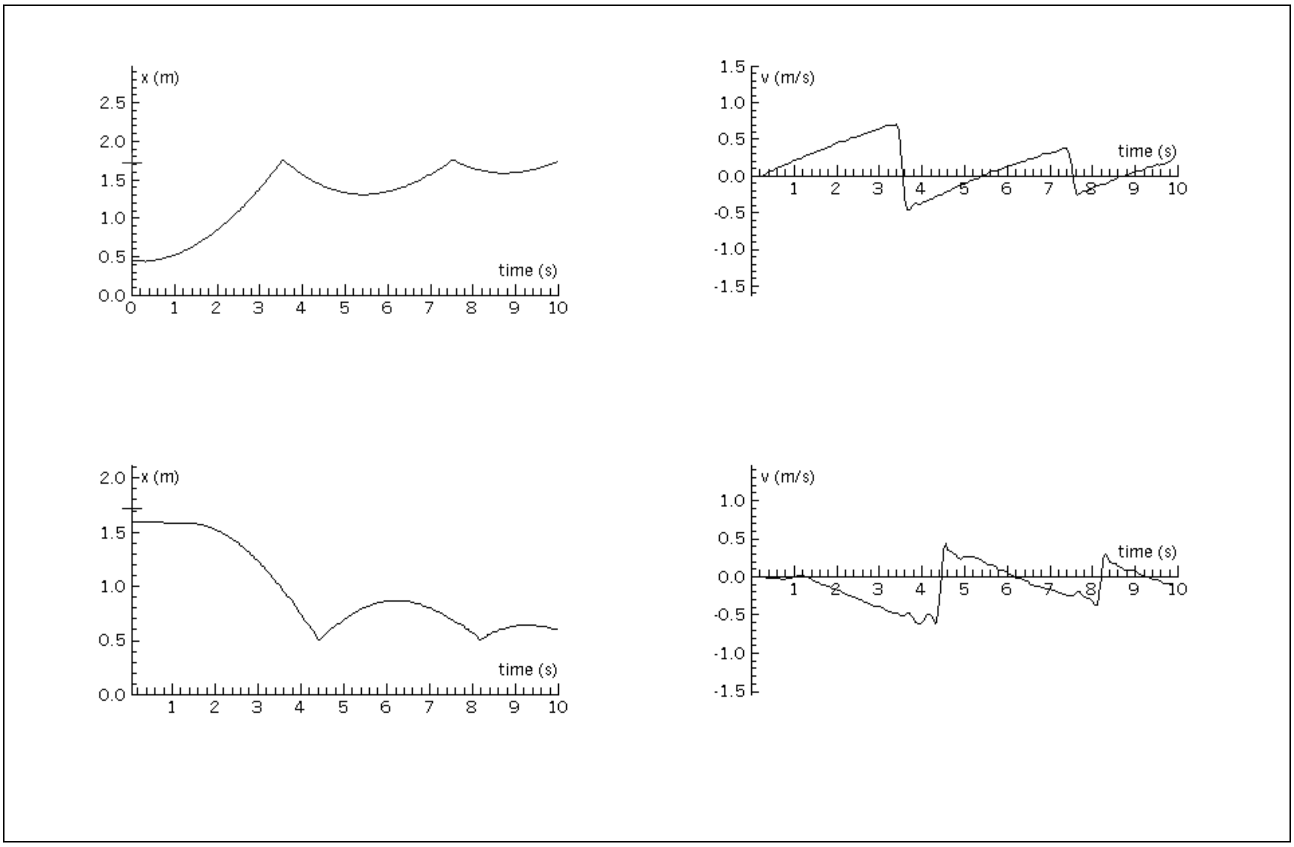
(e) The class correlate the inversions in s(t) and in v(t), identifying which characteristics of the graph are the indicators. Help to become aware that the inversion due to the hit against the bumper are represented in v(t) by a steep step passing through zero while the inversions when the cart reaches the maximum height on the ramp are represented by a linear increase crossing the time axis (see figure below). Ask to compare the values of speed just before and immediately after the inversions, and to explain the decrease in speed after the collision. Note that the slope of the linear sections of v (t) describing the motion uphill is always lower than that of the lines describing the descend and relate this observation with the effects of friction, which is low, but not zero



(f) Have the class: - estimate from the v(t) graph the duration of the two types of inversion; - predict the s(t), v(t) and a(t) when the sensor is at the bottom of the ramp, behind the bumper and could "see" the motion of the cart: - perform the experiment, paying special attention to avoid the cart hitting the sensor; compare predictions with experimental results and, if needed, iterate the PEC cycle.

(g) Discuss the changes in the graphs compared to the situation in which the sensor is on top of the ramp (change of Coordinate System), with particular attention to the inversions. Construct an image with four graphs to compare s (t) and v (t) in these two cases (sensor up and down, see fig. below)

Caption in fig inglese



Four graphs display of s(t) and v(t) of the cart going up/down an incline (sonar on top and on the bottom)

(h) The class compares the two v(t) graphs and discuss how the inversions are represented

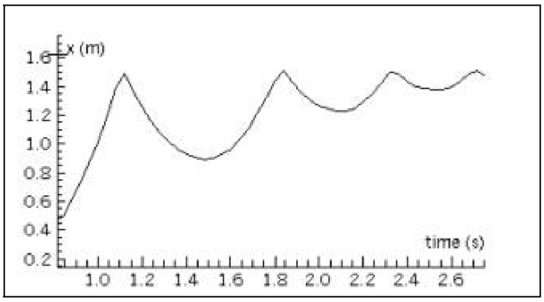
(i) Students discuss ideas about the forces acting on the cart when the motion inverts spontaneously at the top and the bottom of the ramp, because of the impact. If emerges the reasoning that in the inversion on top no force is acting, (for students, often v = 0 imply absence of force), clarify the role of the force of gravity.

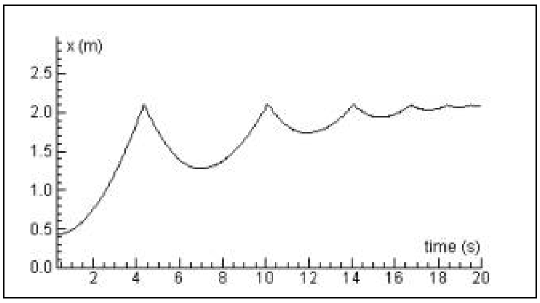
INVFI 5
Experiments on a ball bouncing on the floor: s(t) and v(t) graphs

(a) The sensor is on top of a stand and "sees" several elastic bounces of a ball dropped from rest. With sensor off, the experiment is repeated until conditions are satisfactory. Ask to describe in words of the motion of the ball and to predict the s(t) with a sketch. Record and share the key features emerged.

(b) Select a one graph display (s(t)) and discuss with the class the time interval for the data taking on the basis of what observed before. Sensor on: the students run the experiment. Be careful that the bounces are clearly seen by the sensor, and that there are no artefacts due to the hand that initially holds the ball.. They compare their predictions with the experimental graph and discuss similarities and differences. If needed repeat the PEC cycle.

(c) Ask to identify from the s(t) graph the inversions of motion caused by the bouncing on the floor and those when the ball reaches a maximum height. Have the class load the graph s (t) of the previous experiments (cart down / up, sensor on top); make a two graphs display (two s(t) graphs aligned: cart and ball, see diagram below) and compare the two trends with particular attention on the inversions.





(d) Ask to predict the v(t) graph of the bouncing ball, in words and with a sketch, and to compare predictions and experimental v(t) data and, is needed, to iterate the PEC cycle.

(e) Students discuss the s(t) and v(t) graphs of cart and ball and explain similarities and differences

(f) The experiment is repeated using different materials for the bouncing area while dropping the ball always from the same height. Students discuss the differences in the measured s(t) and v(t) graphs and propose hypotheses to explain them

(g) Elicit ideas on the forces acting at the inversions, and those before and after the impact. Reinforce the concept of impulsive forces and establish similarities with the case of the motion of the cart on the ramp previously studied .

INVFI 6

Experiments on vertical oscillations of a mass-spring system: analysis of s (t), v (t) and a (t) graphs

(a) A spring of known elastic constant with a an attached mass of known value is suspended to a suitable stand. The sensor "sees" the mass from the bottom

(b) Sensor off: have the mass-spring system oscillate starting from different initial conditions: elongation or compression of the spring, initial velocity positive or negative and their combinations. The class discusses the motions with special focus on its inversions. Record and share ideas that emerge.

(c) Sensor on and a one graph display (s(t)). The class negotiate the time range of data collection; perform the experiment; describe in words the graph features with particular attention to the inversions; predict the trend of v(t)

(e) In a two graphs display, (s(t), v(t)), students analyse the trend of v(t) and analyze the correlation with s(t) Have them note the correspondence between maxima/minima of s(t) with zeros in v(t).

(f) Clarify that in the case of the spring-mass system the inversions are not caused by collisions with other bodies. Have students compare the inversions here with the "spontaneous" ones observed for cart and ball.

(g) Help the class to become aware that: - in s (t) any inversion is indicated by a maximum or minimum; - in v (t) any inversion is indicated by a change of sign, through zero

Gulu University

Naples FEDERICO II University

1

Measurements
&
Numbers

(Common) Teaching Path about Measurements

- what a measure is

- Systems of Units, transformations

- measuring tool (range, class, uncertainty,…)

- distribution of measures, average value, errors

- errors analysis and propagation

- ….

Time and Distance Measurements

- what is a clock (length ruler)
- bit of history of clocks (rulers)
- I.S. second (meter) evolution of definitions
- types of clocks (rulers), accuracy, errors
- how to use commercial clocks (rulers)
- measure: < T > +- Δ T; < L > +- Δ L ; …….

Which help from low-cost lab-work?

A low-cost lab-work approach
building on perceptual, commonsense knowledge
using Arbitrary Units (A.U.)

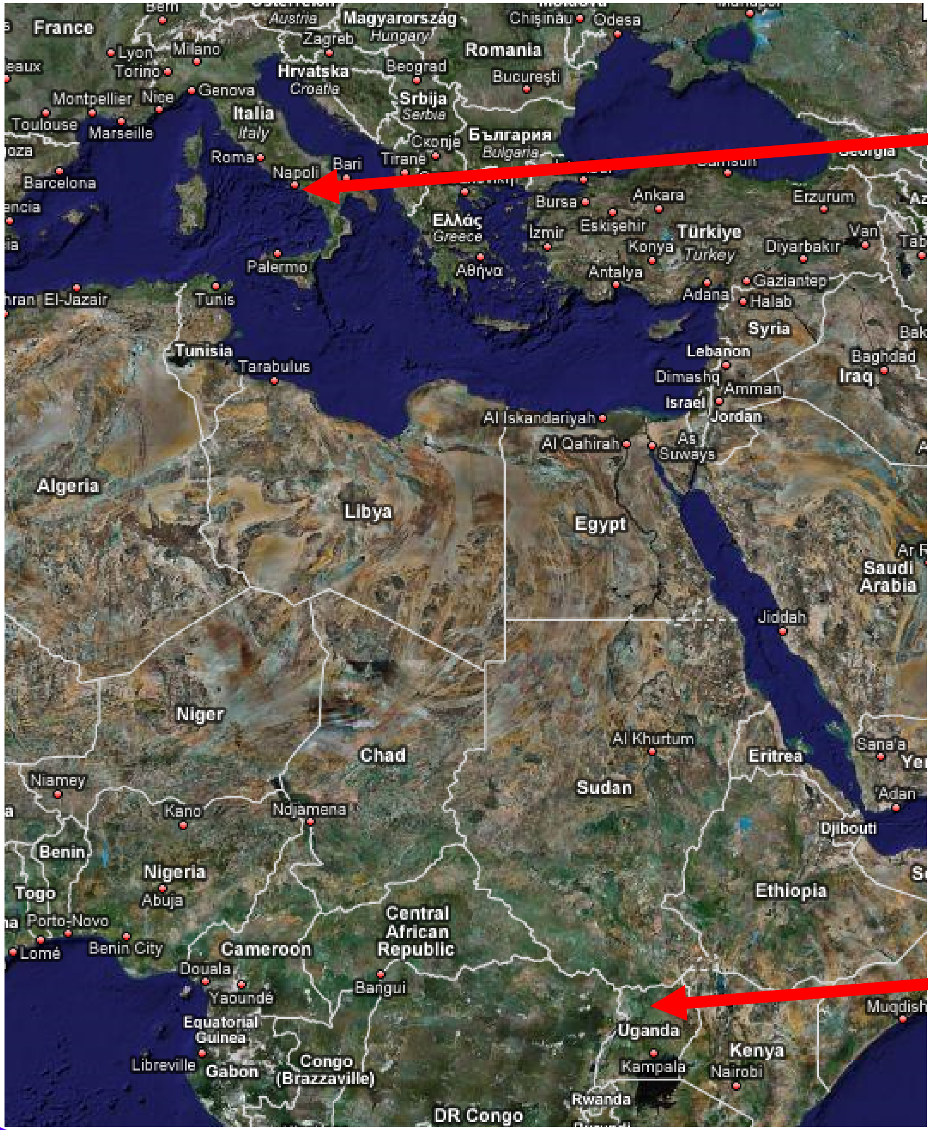
"Clocks" ticking in A.U.

"Rulers" calibrated as you like

Measurement and Error

where this come from?

GULUNAP –SCIENCE Project



Napoli (south Italy)

Federico II Naples University

founded in **1224**

Gulu (north Uganda)

Gulu University

founded in **2002**

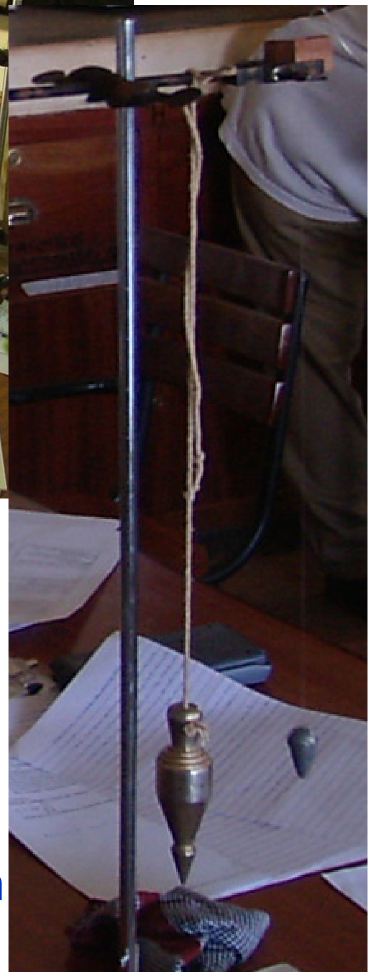
GULUNAP Rationale

- full immersion
- no-cost/low-cost lab-work
- PER results + peer learning
- from memorization
  to active learning
- building critical thinking
- do-it-yourself, local stuff
  lab equipment

Pendula as “ Clocks ”

comparing pendula

measuring pendulum



perfect tools from local market

search for pendulum

ICPE2007

and now ….. NUMBERS

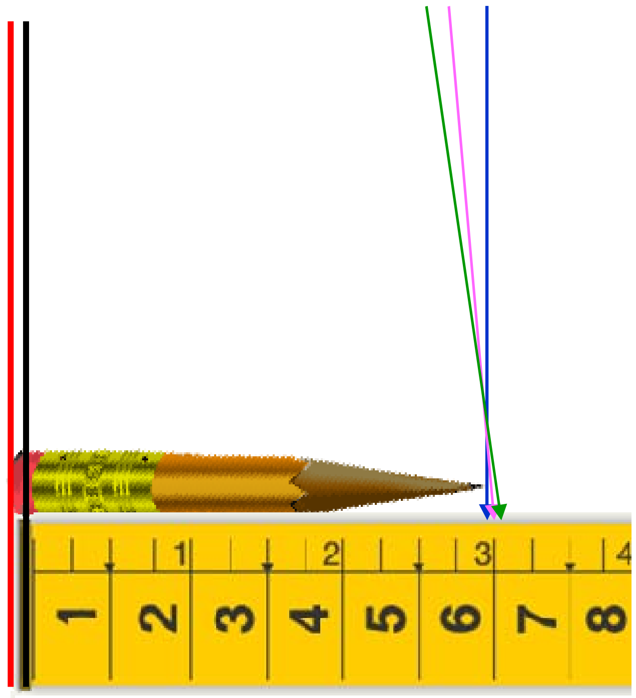
Are 12.32 meters equal to 12.32000 meters ?

Yes for a M**athematician** **NO** for a **physicist**, a **chemist**, a **biologist** etc. (an **experimentalist**) !

Unit of measure

In the result (**direct** or **indirect**) of a **measure** the (*significant*) **digits** do have a precise meaning

Direct Measure of a Quantity



- Comparison with a **UNIT**
  - 5.9 cm
  - 6.0 cm
  - 6.1 cm
  - **....** cm
  - **....** cm

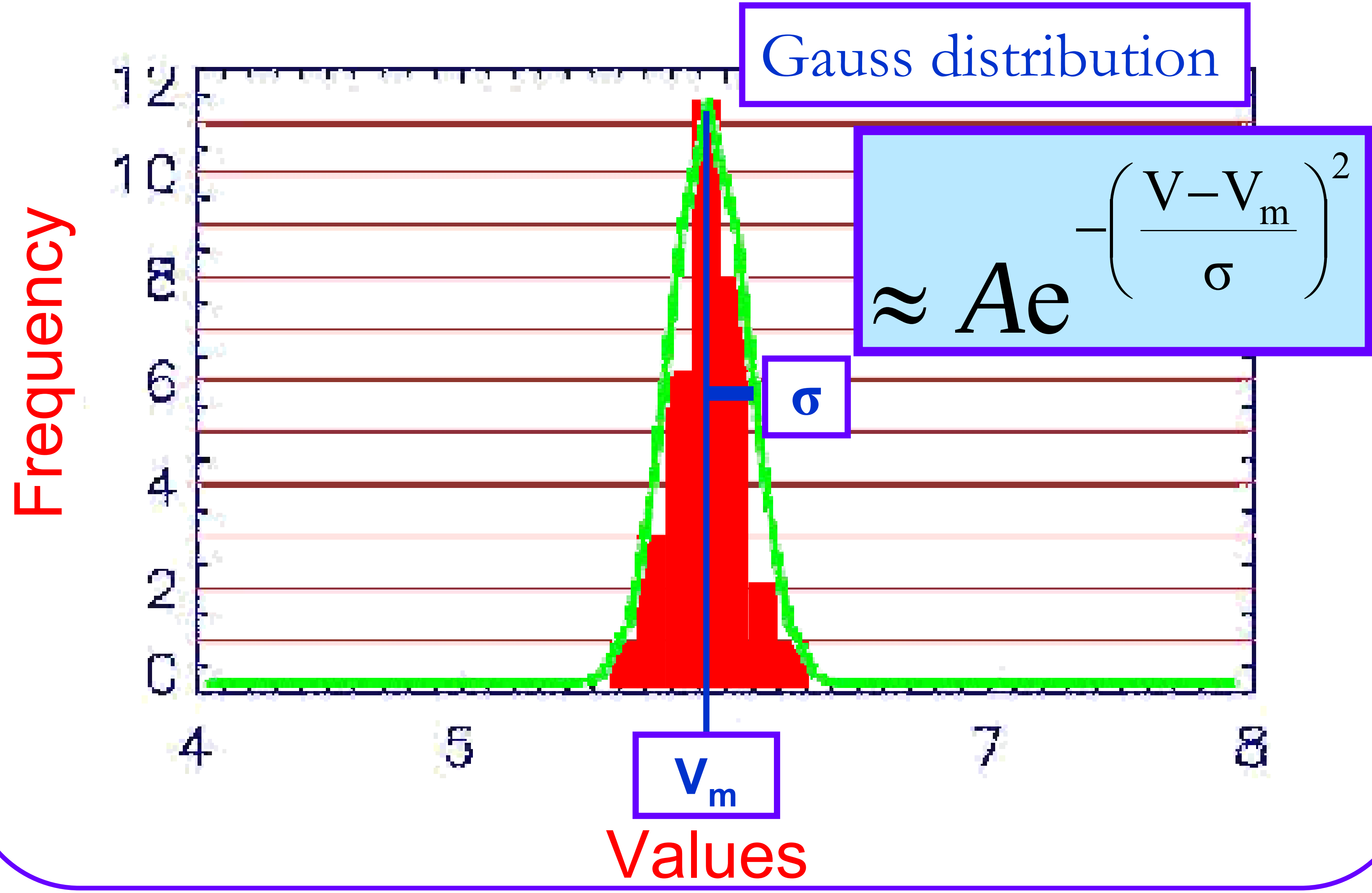
Random Errors (±)

Systematic Errors

If found, can be corrected

(offset, calibration, procedure, measure conditions, preparation, ..)

Distribution of Measures (histogram)

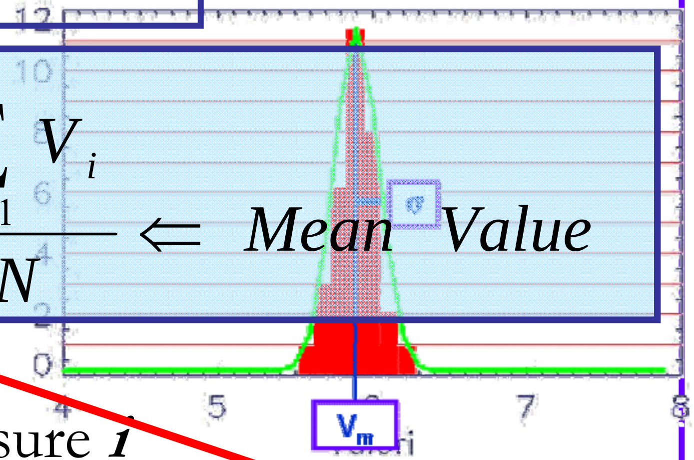


What is the length of the pencil ?

V_1= 5.9 V_2= 6.1 V_3= 6.0 V_4= 5.9 V_5= 5.8 V_6= 6.2 V_7= 5.6 …. V_i=….

N measurements

$$V_m = \frac{V_1 + V_2 + V_3 + \ldots + V_i + \ldots}{N} = \frac{\sum_{i=1}^{N} V_i}{N} \Leftarrow Mean\ \ Value$$

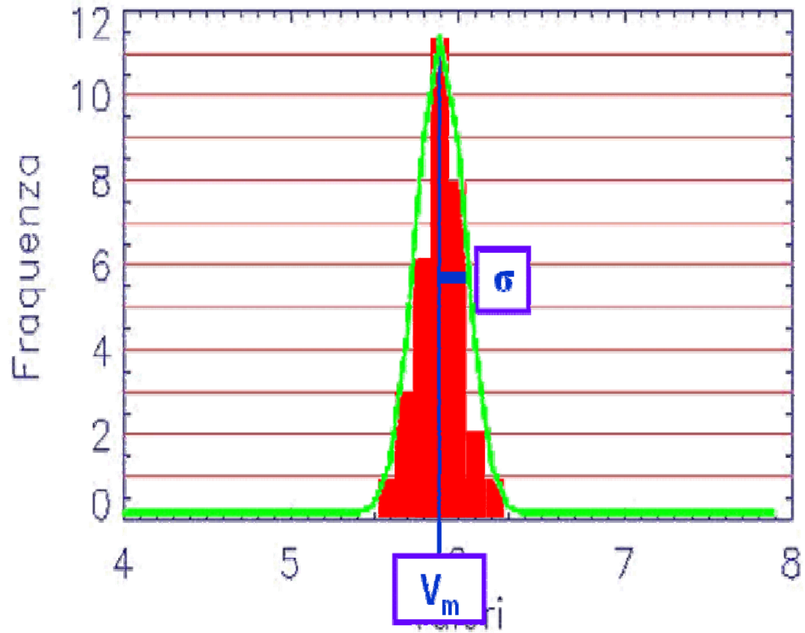


(V_i- V_m) deviation (from average) of measure ***i***

$$\sum_{i=1}^{N}(V_i - V_m) = (V_1 - V_m) + (V_2 - V_m) \ldots + (V_i - V_m) + \ldots = V_1 + \ldots + V_i + \ldots - N V_m = 0$$

What is the length of the pencil ?

An indicator of the histogram width is needed to synthesise how **good** the measure is



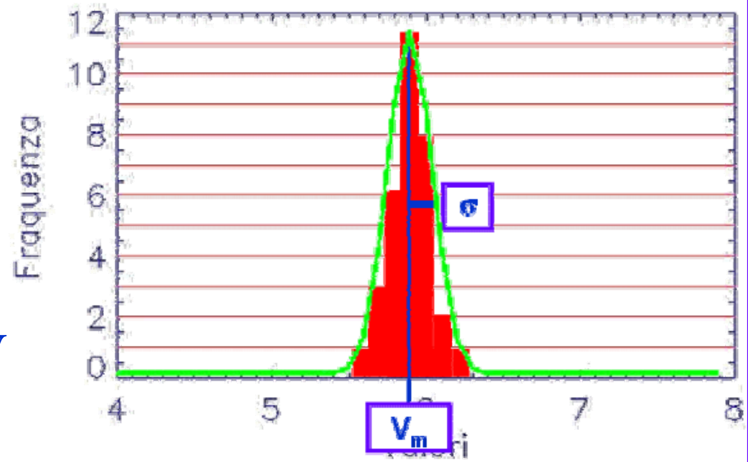
$$\sigma = \sqrt{\frac{(V_1 - V_m)^2 + (V_2 - V_m)^2 + \ldots + (V_i - V_m)^2 + \ldots}{N}} = \sqrt{\frac{\sum_{i=1}^{N} (V_i - V_m)^2}{N}}$$

Standard Deviation σ (or **error**)

What is the length of the pencil ?

The **measure** is written as

$$V_m \pm \sigma$$



It means that, when a new measure is taken under the same conditions, the new value ***V*** has a probability as:

- 68% $(V_m - \sigma) \leq V < (V_m + \sigma)$
- 95% $(V_m - 2\sigma) \leq V < (V_m + 2\sigma)$

Ex: Oscillation Period of a Pendulum

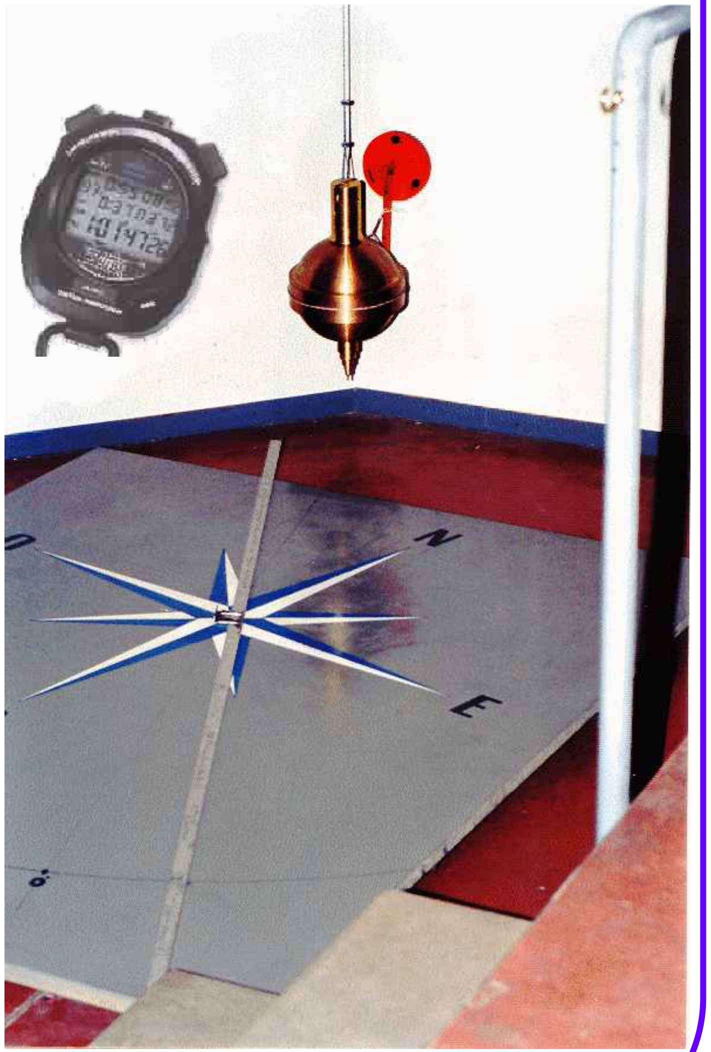
- **12 measures** (in seconds):

15.21	15.43	15.32	15.50
15.61	15.45	15.61	15.24
15.55	15.48	15.35	15.52

$$P_m = 15.43917 \text{ s}$$

$$\sigma = 0.145090 \text{ s}$$

$$P = 15.43917 \pm 0.145090 \text{ s}$$??



Comments on the Example

$P_m = 15.43917$ s $\sigma = 0.145090$ s

(on a pocket calculator … more digits may appear on a different one)

Let's read it:

For a new measure: 68% probability to be in the range
15.29408 - 15.58426

Certain digits

First uncertain digit

First rule: **– *what does it means to write thousandths when the chronometer measure hundredths and the human reaction times are about 0.1-0.2 s ?***

P=15.44 ±0.15

(Numerical Approximation)

Rules to round a number

If the first digit to cancel **(control digit**) is:

a) < 5 → the digits to keep do not change (**approx. by defect**)

b) > 5 → the last digit to keep is increased by 1 (**approx. by excess**)

c) = 5 → the last digit to keep is rounded to the even digit

d) = 50 → rounding by excess or defect

Ex:

17.6712 at 3 digits is (**b**) **17.7**; **17.6472** at 3 digits is (**a**) **17.6**

17.6572 at 3 digits is (**c**) **17.6**; **17.7572** at 3 digits is (**c**) **17.8**

17.7502 at 3 digits is (**d**) **17.7** or **17.8**

Measure of Pendulum Period

$P_m = 15.43917$ s $\sigma = 0.145090$ s

Rule of **Common Sense** $P = 15.44 \pm 0.15$ **Approximation at hundredth of second**

Rule for writing the measure's values:

The significant digits of a measure are the certain digits and the first uncertain digit

$$P = 15.4 \pm 0.15^{(*)}\ \text{s}$$

(*) If the first significant digit of the error (uncertainty) is 1, round the error to 2 digits (if we take out 5 the relative error is 5/10)

Writing of the Measure's Value

Error (uncertainty) explicit: $x \pm \Delta x \quad (x \pm \sigma)$

Error (uncertainty) implicit, given by the last significant digit:

32.5**4** kg→ **±0.005** kg 32.**5** kg→ **±0.05** kg; 3**2** kg→ **±0.5** kg

- Numbers used in calculations may have an extra significant digit, with respect to what are requested for the final value, to minimize inaccuracies coming from rounding
- Measure and error must be written with the same unit
- When calculating, the result has to be rounded according to the number of significant digits of the data that have the minimum of significant digits

$\Delta x = \sigma$	**Absolute Error**
$\Delta x / x$	**Relative Error** or **Fractional Uncertainty**
$100 \times \Delta x / x$	**Percentage Error**

Examples of Measures

	Length of street x=4 km $\Delta x=\sigma=2$ m	Length of rafter x=1 m $\Delta x=\sigma=1$ mm
to write	4000±2 m	1.000 ±0.001 m
ε_r	2/4000=0.0005	0.001/1=0.001
$\varepsilon_{\%}$	0.05%	0.1%

Which is the more accurate (precise) measure ?

Scientific Notation

$10^0 = 1$ $10^1 = 10$ $10^2 = 100$ $10^3 = 1000$ $10^4 = 10000$

$10^{-1} = 0.1$ $10^{-2} = 0.01$ $10^{-3} = 0.001$ $10^{-4} = 0.0001$

Properties: $10^n \times 10^m = 10^{n+m}$ – $10^n : 10^m = 10^{n-m}$

$10^2 \times 10^4 = 10^{2+4} = 10^6$ – $10^2 \times 10^{-5} = 10^{2+(-5)} = 10^{-3}$

$10^2 : 10^4 = 10^{2-4} = 10^{-2}$ – $10^2 : 10^{-5} = 10^{2-(-5)} = 10^7$

N. S.: $y.xxx \times 10^m$ with $1 \leq y \leq 9$ signif. digits

- Simplification of calculations (much less mistakes with pocket calculators).
- Better control of significant digits !!!

Examples of scientific notation

33.5 kg in grams **= 33500 g**

3.35×10^1 kg in grams **= 3.35×10^4 g**

$$\frac{7.52\times10^{3}\bullet3.242\times10^{-7}\bullet1.7\times10^{2}}{2.34\times10^{5}\bullet3.14\times10^{-4}}=$$

Power of 10: **3-7+2-(5-4) = -3**

$$\frac{7.52\bullet3.242\bullet1.7}{2.34\bullet3.14}=5.640716424$$

$= \mathbf{5.6\times10^{-3}}$

Other examples of scientific notation

$$\sqrt[2]{2.32\times10^{8}} = (2.32)^{\frac{1}{2}}(10^{8})^{\frac{1}{2}} = \sqrt[2]{2.32}\times10^{4} = 1.52\times10^{4}$$

$$\sqrt[3]{2.32\times10^{8}} = (232)^{\frac{1}{3}}(10^{6})^{\frac{1}{3}} = \sqrt[3]{2.32}\times10^{2} = 6.14\times10^{2}$$

$$\sqrt[3]{9.37\times10^{-4}} = (937)^{\frac{1}{3}}(10^{-6})^{\frac{1}{3}} = \sqrt[3]{937}\times10^{-2} = 9.79\times10^{-2}$$

Order of Magnitude of a Measure

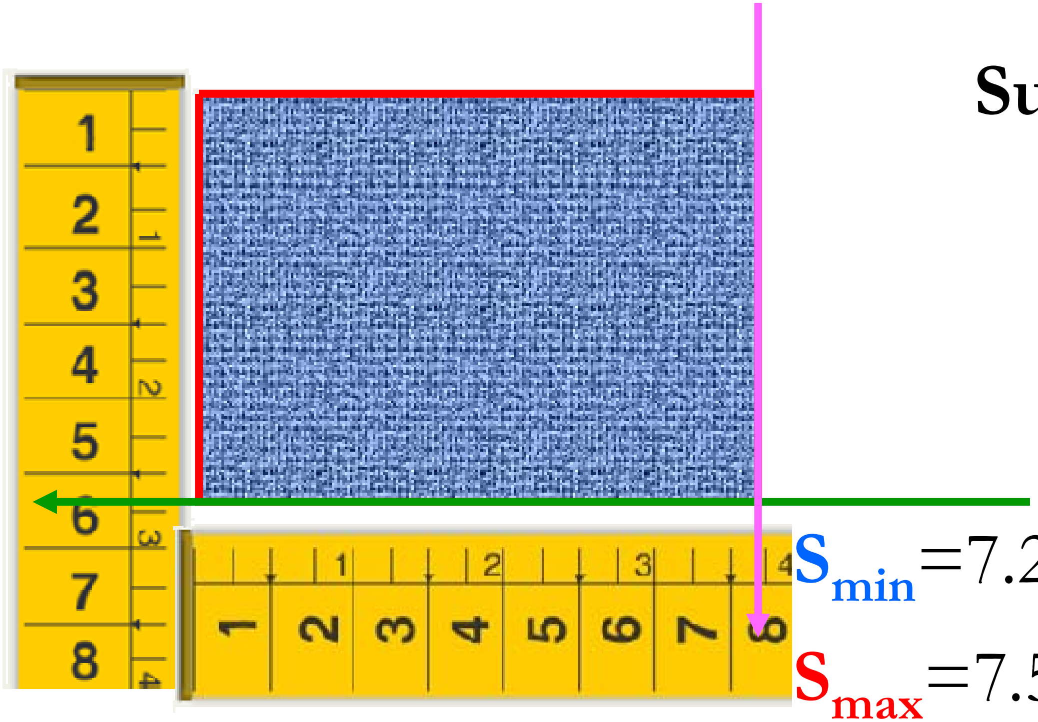
Order of Magnitude (O o M) of **X**

$\rightarrow \mathbf{10^{(\log x)}}$ **approximated to unity**

O o M of 23 = 10 ($\log_{10}$ 23 =1.36)

O o M of 850 = 10^3 ($\log_{10}$ 850 =2.92)

Indirect Measure of a Quantity



Surface S = Base × H

B=7.4±0.15 cm

H=5.3±0.15 cm

S_{min}=7.25×5.15=**37.3375** cm²

S_{max}=7.55×5.45=**41.1475** cm²

68% Probability to have **37.3375 ≤ S < 41.1475**

S = 39 ± 2 cm² (S ± ΔS)

Error in an Indirect Measure of a Physics Quantity

(propagation of error)

$$y = \mathbf{y} \pm \Delta_y \quad ; \quad x = \mathbf{x} \pm \Delta_x \quad ; \quad z = \mathbf{z} \pm \Delta_z$$

$G = f(x,y,z)$ where f is a relation (law) from physics, math, geometry.

$$G = \mathbf{G} \pm \Delta_G$$

$$\mathbf{G} = f(\mathbf{x},\mathbf{y},\mathbf{z})$$

$$\Delta_G = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 \Delta_x^2 + \left(\frac{\partial f}{\partial y}\right)^2 \Delta_y^2 + \left(\frac{\partial f}{\partial z}\right)^2 \Delta_z^2}$$

Error in an Indirect Measure of a Physics Quantity

(more frequent cases)

$G = a\,x + b\,y$ $\qquad \Delta_G = \sqrt{a^2\Delta_x^2 + b^2\Delta_y^2}$

$G = 3x + 2y$ $\qquad x = 4.1 \pm 0.2$ $\qquad y = 2.2 \pm 0.4$

$\Delta_G = \sqrt{9 \bullet 0.04 + 4 \bullet 0.16} = 1$

G=16.7 $\qquad$ **G = 17 ± 1**

$G = x \bullet y$ $\qquad \Delta_G = \sqrt{y^2\Delta_x^2 + x^2\Delta_y^2}$ $\qquad$ **G = 9 ± 1.7**

$G = x/y$ $\qquad \Delta_G = \frac{1}{y^2}\sqrt{y^2\Delta_x^2 + x^2\Delta_y^2}$ $\qquad$ **G = 1.9 ± 0.4**

PHYSWARE
Introduction to Low Cost Kinematics Teaching with Active Learning

KINEMATICS TEACHING, PART 1
Position-Time and Velocity-Time Graphs for Walking Motions

Introduction: Being able to describe the physical world with equations is a central part of physics. In the study of motion physics education research indicates that it is important for introductory physics students to relate a picture or memory of motions they can see to more formal models or representations such as graphs and equations. Thus we suggest that you begin teaching motion by having students describe and make very simple motions in one-dimension. At the same time you can ask students to draw position vs. time graphs of these motions. After students have practice with this and you define the concept of velocity in your teaching, you can have students draw velocity-time graphs using both their own motions and position-time graphs of very simple motions. Students can create a number line using the ruler they constructed earlier. They can also figure out how to time their walking using a pendulum clock.

Objectives

A. To help students learn to translate descriptions of simple motions into those motions.

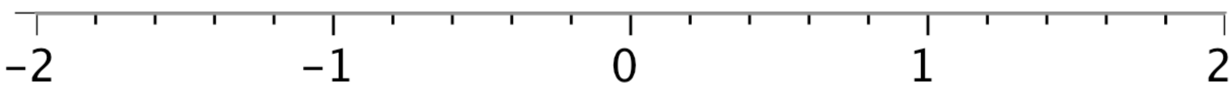
B. To help students learn how to create position-time graphs of their motions.

C. To help students reproduce motions or describe them by looking at a position-time graphs.

D. To introduce the definition of velocity to students and help them create a very simple velocity-time graphs from a position-time graphs.

Representations

Individual Question: Consider how to describe motion along a line. Suppose you put a number line on a floor that is 4 meters long. Then you choose a spot on the line and move slowly along the line at a constant velocity for about 15 seconds. You would like to send a letter to a friend who knows physics and describe what you did. How many *different* ways can you think of to describe your motion to your friend.



Number Line

Note: Obviously one of your "representations" can be in *words*. What other ways can you describe your motion?

Discussion: Join a small group of 2, 3 or 4 people and discuss the representations you and your group thought of. Then write down or draw any new representations that your group discussed.

Using Position vs. Time Graphs and Words to Describe Walking Along a Line
We would like to have you and others in your group each: (1) draw a Position-Time graph of some walking motions and (2) describe each motion in words. Finally you will compare your descriptions with others and see if you agree. **NOTE:** *We want you to use what you learned in yesterday's session about fundamental distance and time measurements to establish meters and seconds. Just approximate a 1 meter distance and a 1 second time interval and use these "standards" you have invented consistently! (NO DIGITAL STOP WATCHES ARE ALLOWED)*

Step 1-Make a Number Line: Before you start this activity make a number line that is approximately 4 meters long like the one on page 1. Use the floor space assigned to you. You can use some of the following items to help you create your line:

- 1 Roll of Masking Tape
- 10 Sheets of A4 Paper (good one side is fine)
- 1 Marker Pen
- 1 Ball of String

Step 2-Practice How to Count Out Approximate Seconds: Work with your partners to figure out how to count at about 1 second per number. (Remember, you are not allowed to look at a watch or clock during your practice!)

Step 3-Choose a Simple Motion: Three of the members of your group will take a turn walking in a *different* simple pattern for the other members. Each of you will be asked to: (1) watch a motion; (2) draw a **Position-Time graph** of the motion (using approximate seconds and approximate meters) with a pencil that has a good eraser on it; and (3) use words to describe the motion you saw. Sketch your graphs and write your descriptions in the boxes on the next page. Next, think about how you can walk the motion you have been assigned. Each member of the group will have a turn to walk in a different pattern.

a. Start at the –2 m point on the number line and walk slowly and steadily toward the +1 meter point at a rate of 1 meter per each 5 seconds. Your total walk should take about 15 seconds.

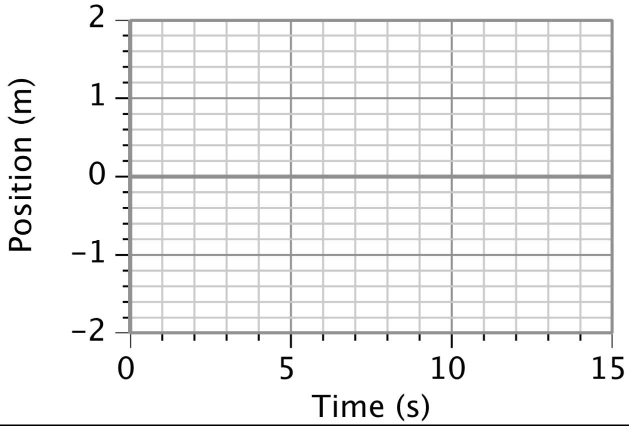
b. Start at the +1 m point on the number line and walk slowly and steadily toward the –2 meter point at a rate of 1 meter per each 5 seconds. Your total walk should take about 15 seconds.

c. Start at the –1 m point on the number line and walk slowly and steadily toward the +2 meter point at a rate of 1 meter per each 4 seconds and then when you reach the +2 meter point stand still for 3 seconds. Your total walk should take about 15 seconds.

d. Start at the –2 m point on the number line say "go" and stand still for three seconds. Then walk slowly and steadily toward the +2 meter point at a rate of 1 meter per each 3 seconds. Your total walk should take about 15 seconds.

Walker 1 Name: ________________

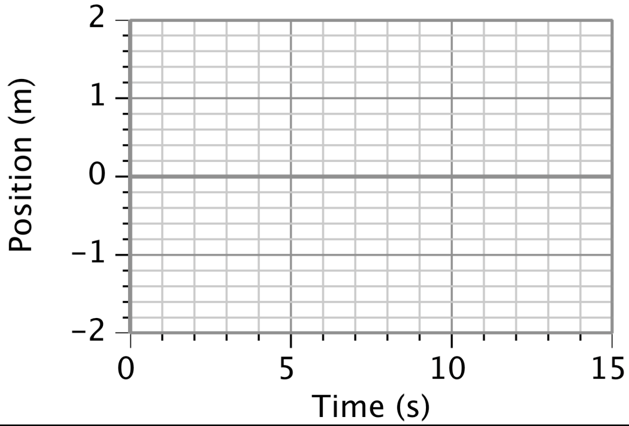
Description of Motion 1 in Words:



Discussion 1: Compare your results with those of your partners. Then make any changes to your description and graph. If needed, make you graph more accurate using a dotted line.

Walker 2 Name: ________________

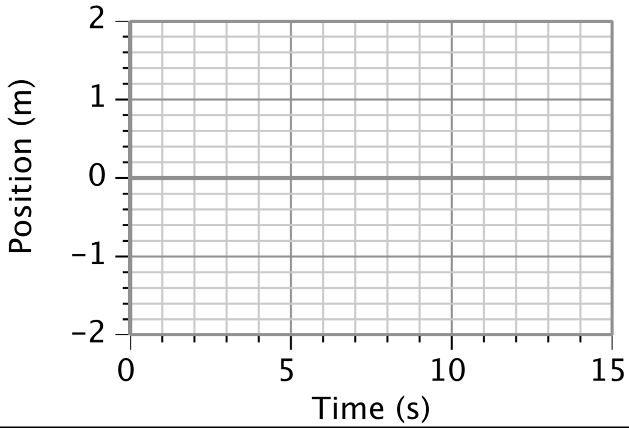
Description of Motion 2 in Words:



Discussion 2: Compare your results with those of your partners. Then make any changes to your description and graph. If needed, make you graph more accurate using a dotted line.

Walker 3 Name: ________________

Description of Motion 3 in Words:

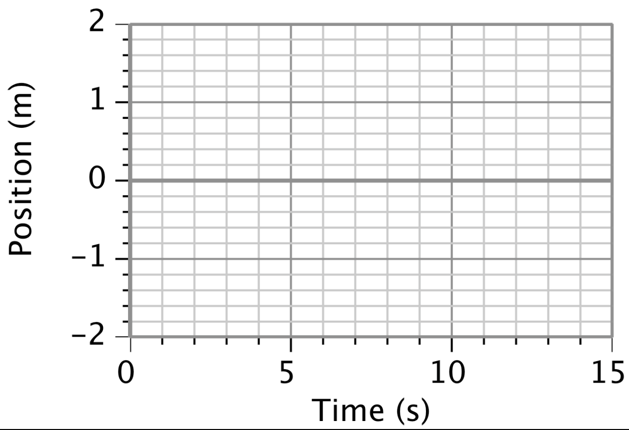


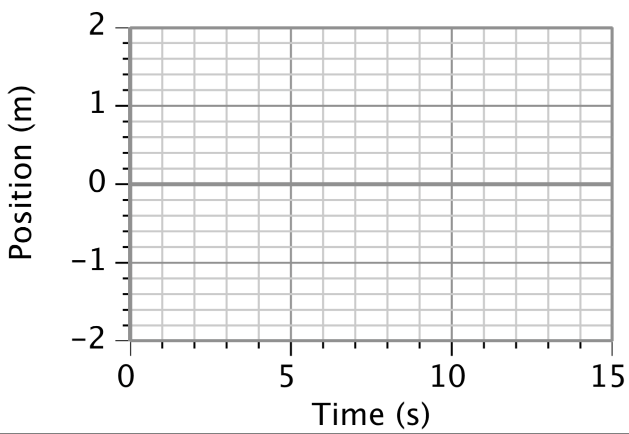
Discussion 3: Compare your results with those of your partners. Then make any changes to your description and graph. If needed, make you graph more accurate using a dotted line.

Step 4-Invent a More Complicated Motion: Each of you should think of a more complicated walk. For example, you might pick a place to start on the negative (–) part of the number line and walk slowly in the positive (+) direction for a few seconds, stand still for a few seconds and walk more rapidly than before in the negative direction for a few seconds. *Describe Your Idea for a More Complicated Walk:*

Step 5-Describe More Complicated Motions: 1 or 2 members of your group should take a turn walking in a more challenging pattern for the group.

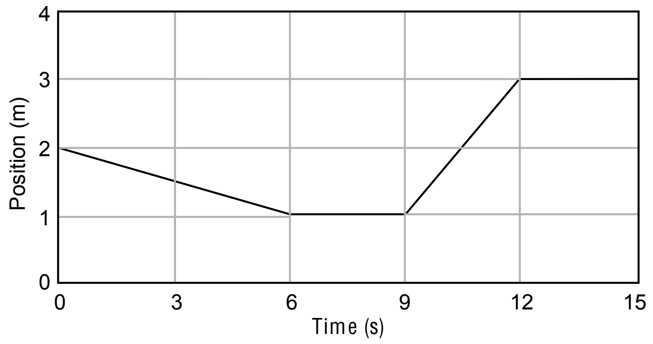
<table>
<tr>
<td>Walker 4 Name: ________________

Description of Motion 4 in Words:</td>
<td>
</td>
</tr>
<tr>
<td colspan="2">Discussion 4: Compare your description graph with your partners and make any changes to make your description. If needed, make you graph more accurate using a dotted line.</td>
</tr>
<tr>
<td>Walker 5 Name: ________________

Description of Motion 5 in Words:</td>
<td>
</td>
</tr>
<tr>
<td colspan="2">Discussion 5: Compare your description graph with your partners and make any changes to make your description. If needed, make you graph more accurate using a dotted line.</td>
</tr>
</table>

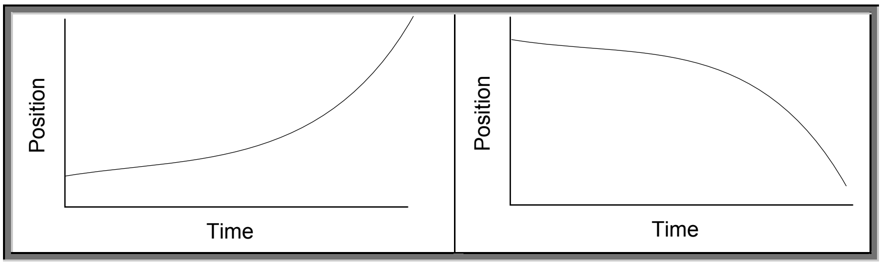
Step 6-Describe and Reproduce Motions Shown in Position vs. Time Graph[1]: Let's turn the activities you've been doing around.

a. We'd like you to look at the graph shown on the right and describe the motion you think it depicts in words. Then talk about your description with your partners and make any corrections that seem necessary.



b. You or one of your partners should practice walking in the pattern described by the graph Then talk about the walk with your partners and make any suggestions for improvements. You and your partners should practice the walk some more.

c. Consider the two graphs that follow and write down how you should move to produce a position vs. time graph for each of the shapes shown below. Then practice making the motions you have described.



Graph 1 answer:

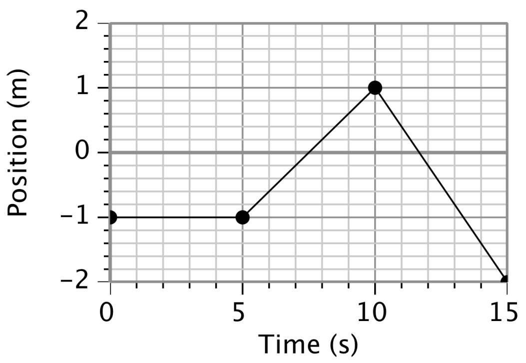
Graph 2 answer:

[1] The following materials are adapted from Unit 3 of the Workshop Physics Activity Guide (John Wiley & Sons, 2004)

d. What is the general difference between motions that result in a straight line position vs. time graph and those that result in a curved position vs. time graph? You can discuss this with your partners if you like.

Step 7: Using a Velocity vs. Time Graph to Describe a Walking Motion

1. The position vs. time graph shown below represents the idealized motion of someone walking in a straight line. Use the graph to calculate the average velocity for the 3 time intervals shown to the right of the graph.

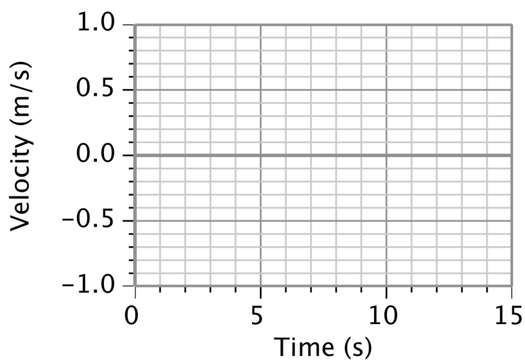


[1] $0\ \text{s} \leq t \leq 5\ \text{s}$

[2] $5\ \text{s} \leq t \leq 10\ \text{s}$

[3] $10\ \text{s} \leq t \leq 15\ \text{s}$

2. Sketch a Velocity-Time graph on the right.



3. Describe the motion in words in terms of velocity at the different times. You can use terms like speed and direction. When is the direction of the walker negative? When is it positive? Then compare your descriptions with your partners and see if you agree. Go ahead and change any answers you think are incorrect.

NOTE: The next 5 pages show an assignment taken from the *University of Washington Tutorial HomeWork on Representations*. The first 4 pages would make good follow up exercises for students. If there is time before the discussion starts you may want to try some of these.

Wrap Up Discussions:

1. Join with the instructors and other workshop participants to describe some of the teaching ideas used in this introductory lesson. Write down some ideas:

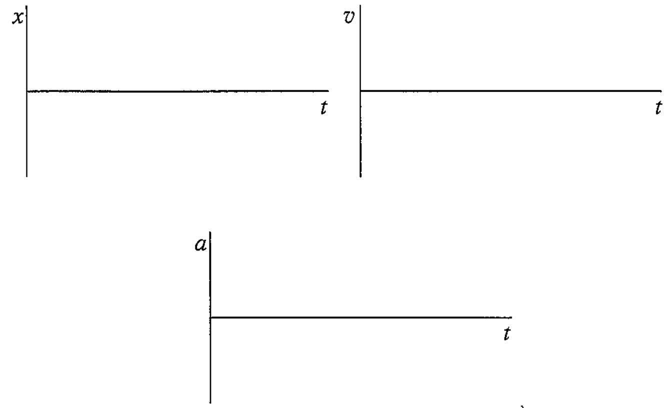
2. Join with the instructors and other workshop participants to discuss ways that this lesson could have been improved. Write down some ideas:

2. There are several answers for most of the situations in the previous problem. Find *at least* one other answer to the three motions repeated below.

Constant positive acceleration

Description of motion:

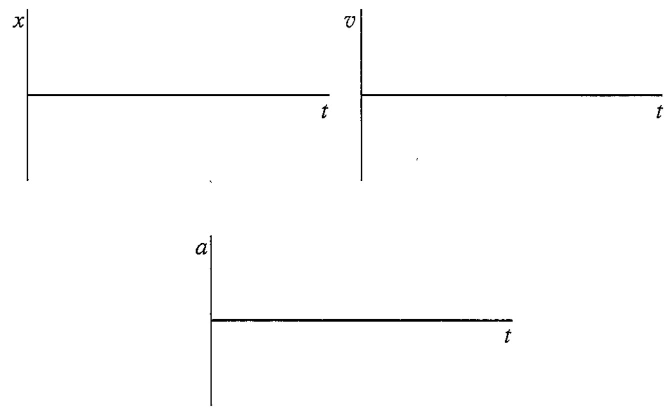
Track:



Constant zero acceleration

Description of motion:

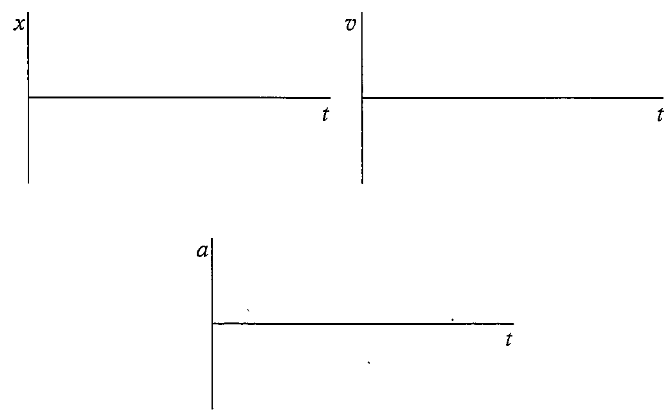
Track:



Constant negative acceleration

Description of motion:

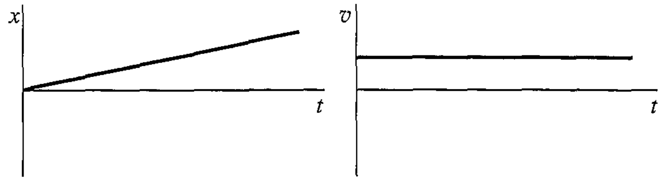
Track:



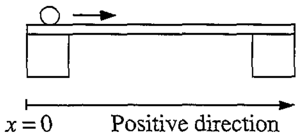
Constant positive velocity

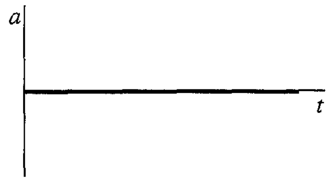
Description of motion:

Move at a constant speed away from the origin.



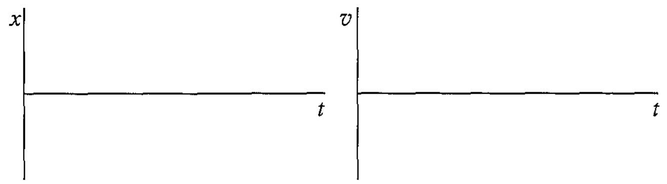
Track:



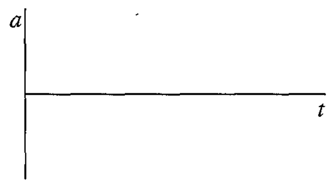


Constant zero velocity

Description of motion:

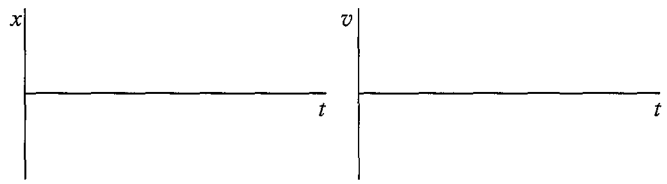


Track:

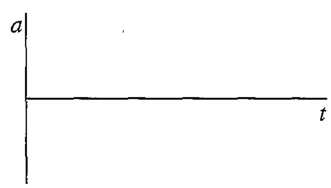


Constant negative velocity

Description of motion:



Track:



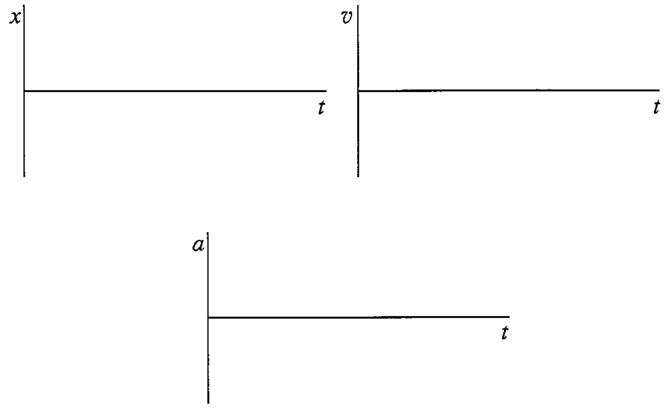
REPRESENTATIONS OF MOTION

Name ______________________

Constant positive position

Description of motion:

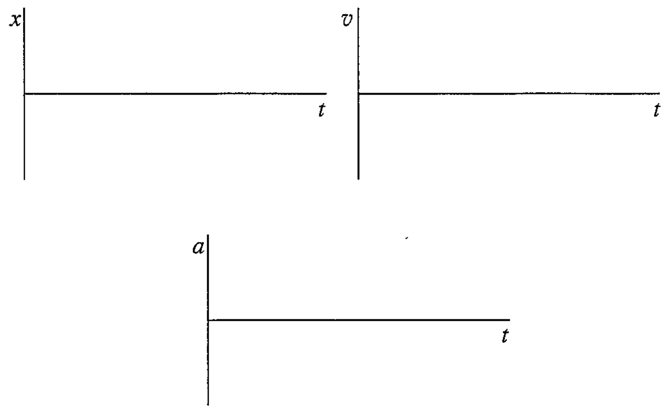
Track:



Constant zero position

Description of motion:

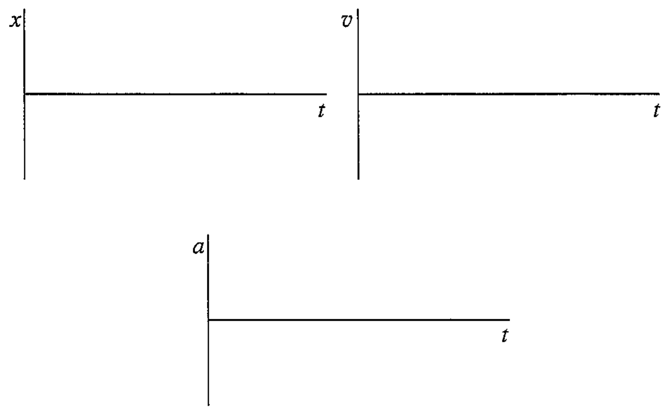
Track:



Constant negative position

Description of motion:

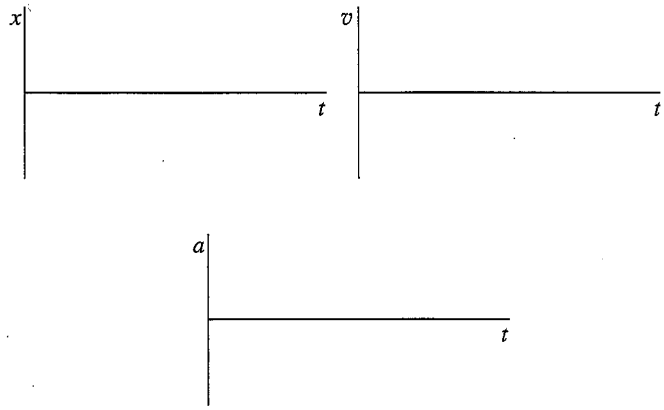
Track:



Constant positive acceleration

Description of motion:

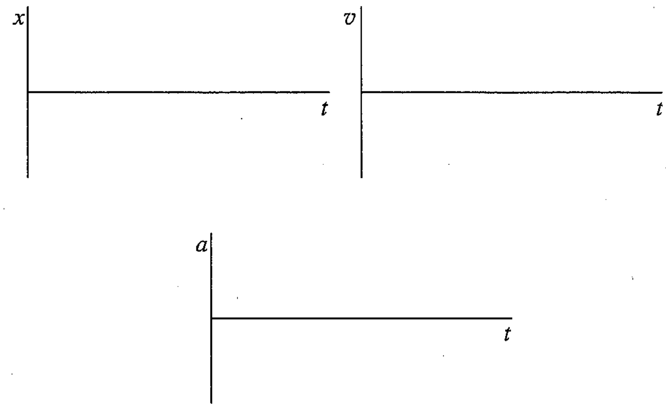
Track:



Constant zero acceleration

Description of motion:

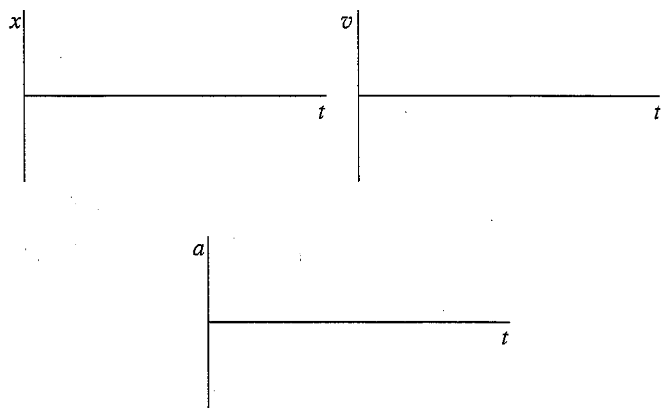
Track:



Constant negative acceleration

Description of motion:

Track:

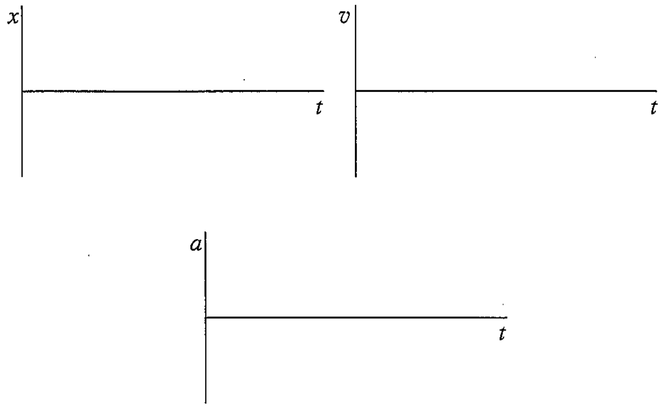


Name ______________

2. There are several answers for most of the situations in the previous problem. Find *at least* one other answer to the three motions repeated below.

Constant positive acceleration

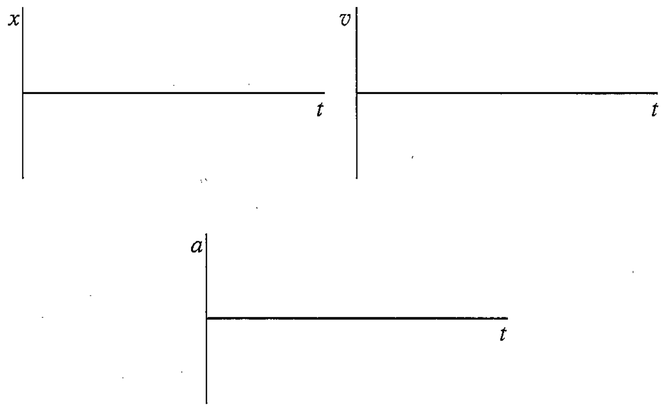
Description of motion:



Track:

Constant zero acceleration

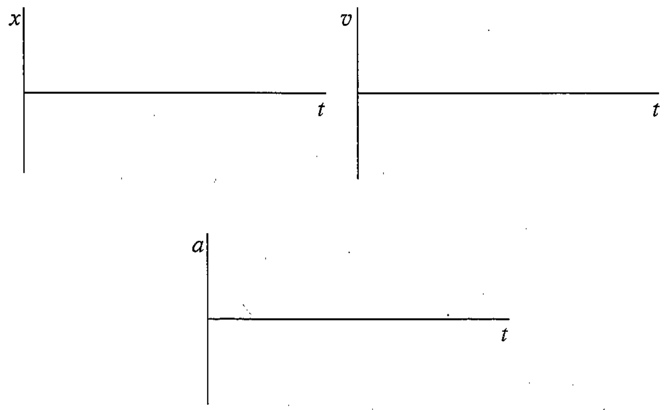
Description of motion:



Track:

Constant negative acceleration

Description of motion:

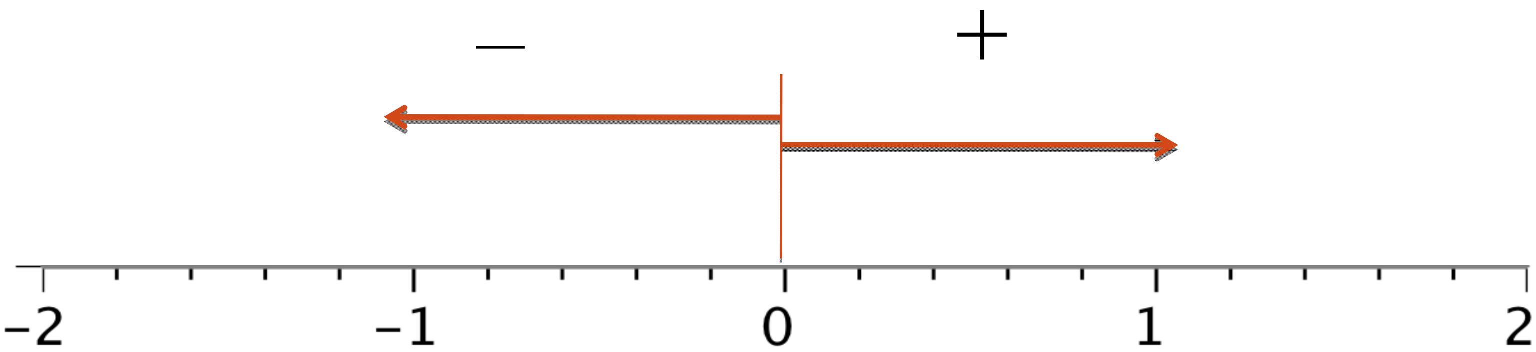


Track:

Representations of 1D Motion

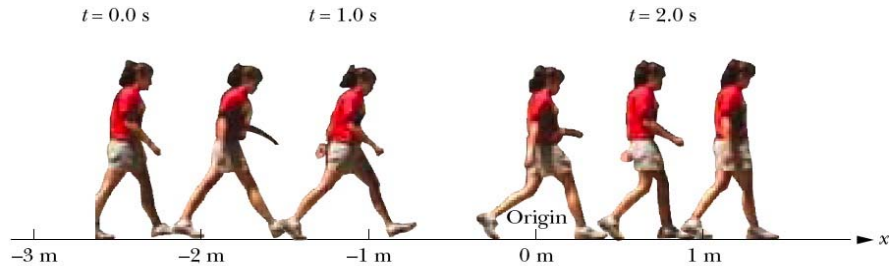
Basic Introduction

Define a Number Line



- **Words:** Start from rest and walk straight for about about 3 meters while speeding up, then slow down

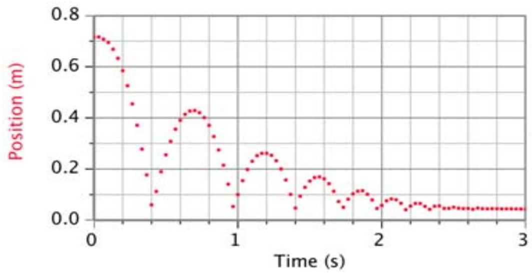
- **Motion Diagram:**



- **Velocity Vector Diagram:**

GRAPHS

- **Position vs. Time Graph:**



- **Velocity vs. Time Graph:**

- **Acceleration vs. Time Graph:**

Equations

- For example, constant velocity

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Introduction to Low Cost Kinematics Teaching with Active Learning

KINEMATICS TEACHING, PART 2

Position, Velocity & Acceleration for Steady Motions

Introduction: Many common motions such as walking, running, or bicycling can involve steady motion (constant velocity), speeding up steadily when getting started (possibly with constant acceleration), and slowing down steadily when stopping (also possibly with constant acceleration). Students can start simply by learning to measure the position and time of a person walking along a number line using the basic measuring tools they constructed (ruler and pendulum clocks). They can then plot position-time graphs and sketch velocity-time graphs for steady walking motions. Next, students can replicate these measurements for a marble rolling on a flat table that is level. This gives them experience with making measurements and plotting and interpreting very simple graphs. The goal in this part of our series on teaching kinematics is to prepare students to engage in future work with constant accelerations.

Objectives for this Session

A. To help students learn to measure position and time for steady motions such as a person walking along a number line or a marble rolling along on a smooth, level table.

B. To help students learn to plot position-time and velocity-time graphs of steady motions at different speeds and in both the positive and negative directions.

C. To help students learn to draw a motion diagram of a ball rolling on a level surface.

D. To introduce acceleration as the rate of velocity change and understand why a = 0 for all constant velocities regardless of the magnitude and direction of the moving object.

STEADY WALKING MOTIONS

Step 1-Gather What You Need:

- 1 Number Line
- Basic equipment for measuring length and time (Pendula, Ruler)
- 6 Small Coins (from any country in the world)
- String and a pencil with an eraser

Step 2-Practice Counting Approximate Seconds: Work with your partners to figure out how to use the pendulum clock you made earlier to help you measure times. You may need to count numbers at about 1 second intervals (or 2 or 3 second intervals as needed for measurements). Remember, you are not allowed to look at a watch or clock as you do this. Practice calling out at equal times intervals by saying the equivalent (in your native language) of “now”, “now”, “now” and so on.

Step 3-Practice Walking with a Steady Velocity in the Positive Direction: Two of the members of your group will take a turn walking in a positive direction at *different* speeds (one is slow and the other faster). The slow walker should practice walking slowly enough that it takes about 15 seconds or less to walk from one end of the number line to the other. The faster walker should try to walk so that it takes about 8 seconds to “walk the line.”

Step 4-Practice Marking a Walker's Position: As a walker moves along the number line you will want to determine his or her position along the line by having the remaining partners either call out time or place small coins along the number line at each time that is called out. Since a person is not a point object, you need to decide what part of the walker determines where he or she is. Perhaps vertically below the person's waist is OK.

Step 5- Measure and Record Positions for Two Walkers Moving in the Positive Direction: As each walker moves along the number line at a steady velocity you will want to determine his or her position along the line by placing a small coin on the number line at each announced time (figure out if you want to use 1, 2, or 3 pendulum ticks for each "now") so that faster walk along the line requires about 5 markers. Determine position and time units for the slower and faster walks. Then fill in the data tables for each walk.

SLOW WALK: Name______________________________

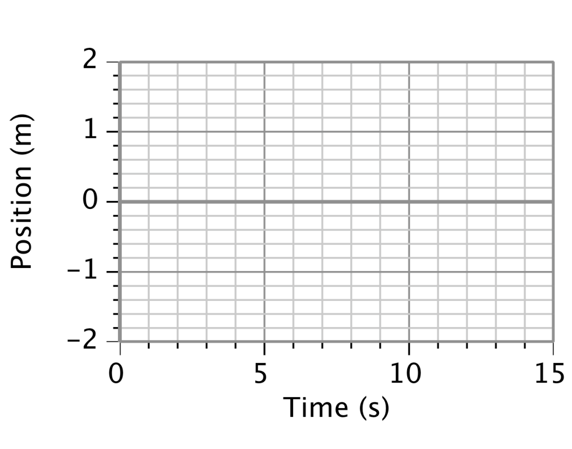
Time ( )					
Position ( )					

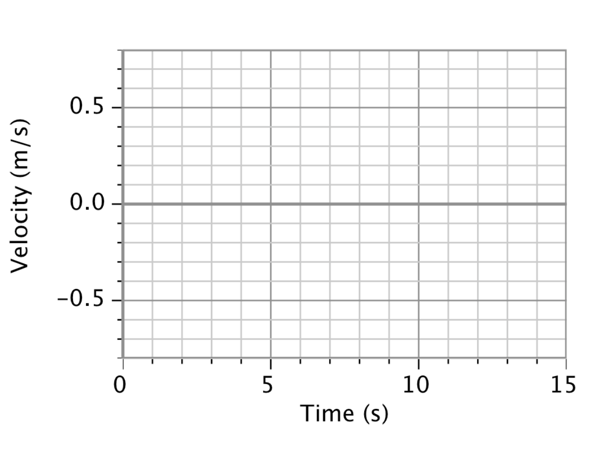
FASTER WALK: Name______________________________

Time ( )					
Position ( )					

Step 6- Draw Position Graphs of the Walking Data: Use the left graph frame below and a pencil to plot position-time graphs for both your walkers. Use a different symbol for each plot such as:

Slow = o   Faster = +





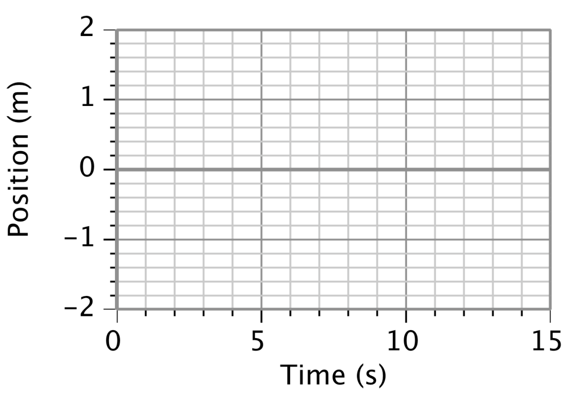
Discussion: Compare your predictions with those of your partners. Then make any changes to your graph to make it more accurate.

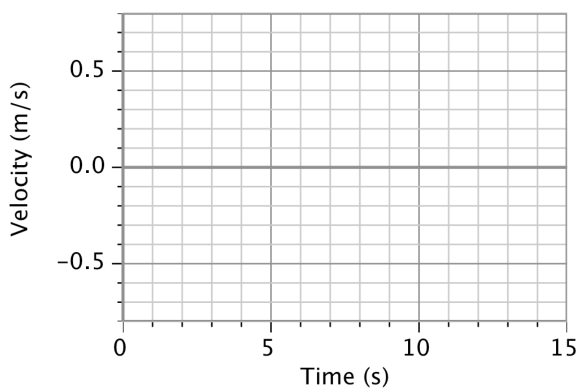
Step 7-How Constant are the Velocities You Measured? Assume that you have already learned that velocity is defined as the rate of change of position and that when motion is steady for a period of time the slope of its velocity graph is a constant. Although there are uncertainties in your measurements, do the graphs indicate that the velocity of each walker was fairly steady? Explain

Step 8-Draw Approximate Velocity-Time Graphs of the Motions: If you have approximately straight lines for your Position-Time graphs, then calculate the slope of each line. Use these calculated slopes to draw idealized lines representing the Velocity-Time graphs for the slow motion and then for the faster motion. Use the Velocity-Time graph frame for Step 6 on the previous page and label the lines faster and slower. Show your slope calculations in the space below and explain how you made them.

Step 9- Predict Motion Graphs for Walking Steadily in the Negative Direction: Suppose the two walkers each start at the +2 m mark on the number line and walk toward the -2 m mark. Assume that each one used exactly the same speed as before. On the graph frames below use a pencil to sketch your predicted position-time graphs for both walkers. Now sketch your predicted velocity-time graph lines. Label each line "slow" or "fast."

A PREDICTION: WALKING IN A NEGATIVE DIRECTION





Discussion: Compare your graphs with those of your partners. Then change your graphs if your partner convinces you that his or hers makes more sense.

STEADY ROLLING MOTIONS

In the future we want you to be able to determine the position, velocity and acceleration of motions along a ramp and finally the vertical motions of a small fairly dense object such as a coin, a small ball or a marble that falls freely. But, in this session we will start by considering the motion of a marble on a flat table that is level. Then in the future you will be working with more complicated motions for which the velocity of the object changes – such as motions associated with rolling on a tilted table or vertical free fall.

Step 1-Gather What You Need:

- Basic equipment for measuring length and time (Pendula, Ruler)
- 6 Small Coins (from any country in the world)
- A marble or a small smooth ball
- A level table with a flat surface (or a 2 meter length of level floor)
- A few sheets of paper and a pencil with an eraser

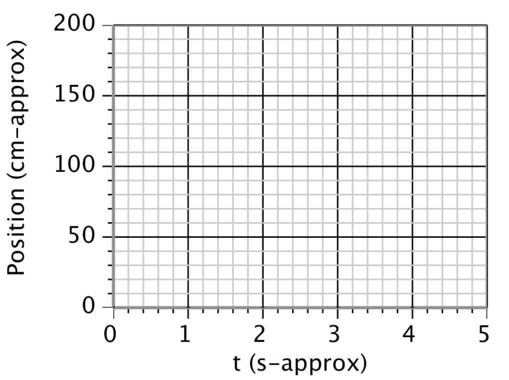
Step 2-Level Your Table: Since the floor or the table legs may be uneven, use your marble to figure out how to find a flat level length of table. (Assume that a marble placed on various parts of the table will not roll unless it is pushed.) When you give your marble a push on the level table, does it seem to move at a constant velocity? If not try to change things so it does. This may be quite challenging for your students.

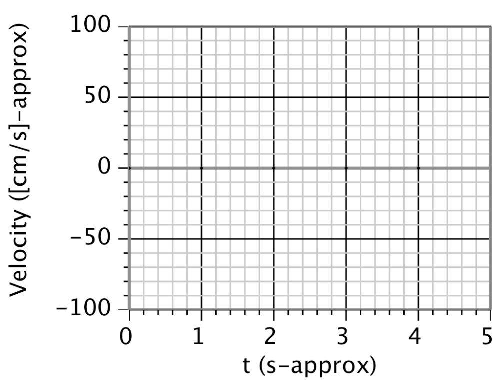
Step 3-Obtain Position-Time Data for the Rolling Marble or Ball: Choose an origin near one end of the table and define a positive direction. Figure out how to obtain position time data for a marble rolling along the table in the positive direction. Set up a rolling speed that allows you to place coins at 4 or more locations along the table. Record your best data in the table below.

LEVEL TABLE MARBLE OR BALL ROLL DATA

Time ( )					
Position ( )					

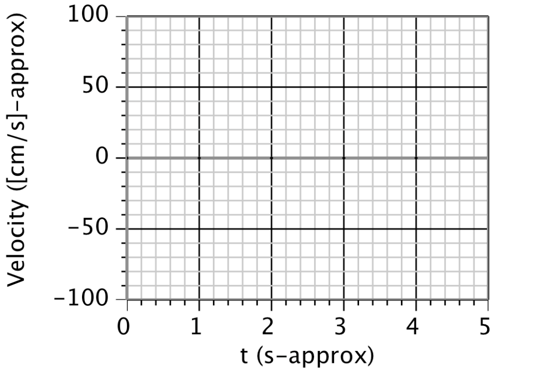
Step 4-Plot Your Data: Plot your position-time data using the graph frame below. You'll have some uncertainties in your data, but do the points seem to lie along a line? If so, estimate the slope of the line and sketch an idealized velocity-time graph below.

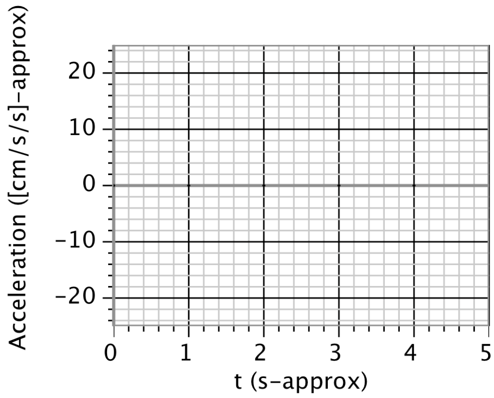




Discussion: Compare your graphs with those of your partners. Then change your graphs to make them more accurate.

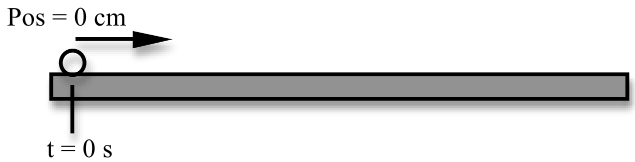
Step 5-Plot an Acceleration Graph for Your Steady Motion: Copy the sketch you placed in the Step 4 velocity-time graph below. Then use the definition of acceleration as change in velocity near a given point to sketch an idealized acceleration-time graph below.





Discussion: Compare your graphs with those of your partners. Then change your graphs to make them more accurate.

Step 6-Create a Motion Diagram for your Rolling Object: Remember that a motion diagram is like a strobe photo or one-dimensional plot of the motion you are studying. You should draw the location of your object at equal time intervals.



NOTE: The 5 pages at the end of the Part 1 Kinematic Materials show an assignment taken from the *University of Washington Tutorial HomeWork on Representations*. The first 4 pages would make good follow up exercises for students. If there is time before the discussion starts you may want to finish some more of these exercises.

Wrap Up Discussions:

1. Join with the instructors and other workshop participants to describe some of the teaching ideas used in this introductory lesson. Write down some ideas:

2. Join with the instructors and other workshop participants to discuss ways that this lesson could have been improved. Write down some ideas:

Representations of 1D Motion

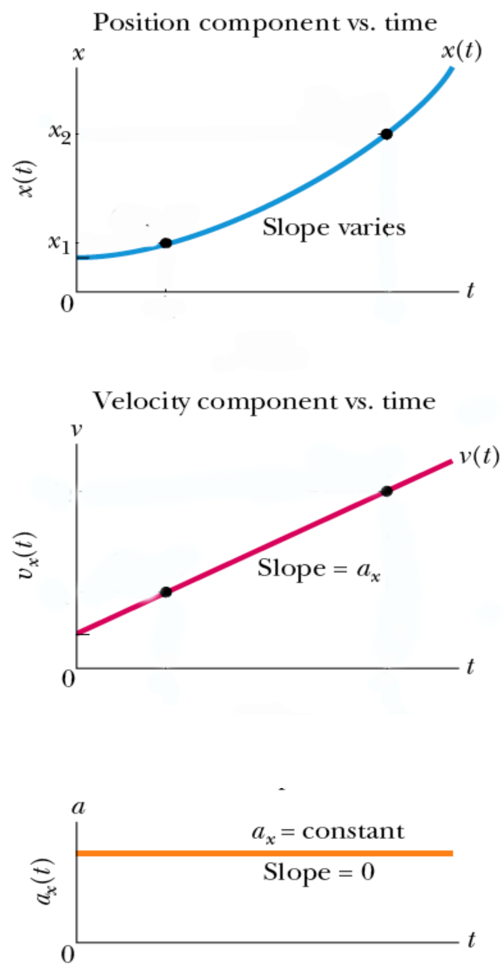
Linking Motion Diagrams, Graphs and Equations

GRAPHS

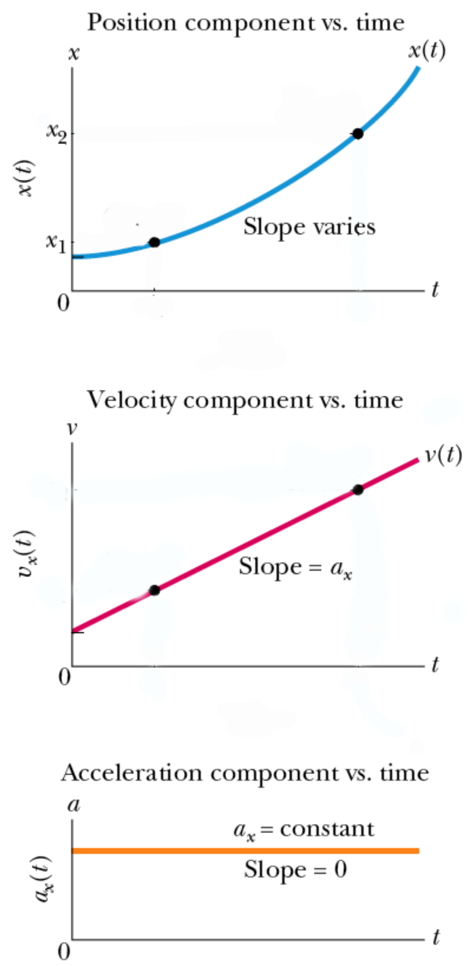
- **Velocity vs. Time Graph:**

- **Acceleration vs. Time Graph:**

Constant Acceleration Graphs



Constant Acceleration Graphs



Equations

- Constant Velocity

Moving steadily in a positive or negative direction

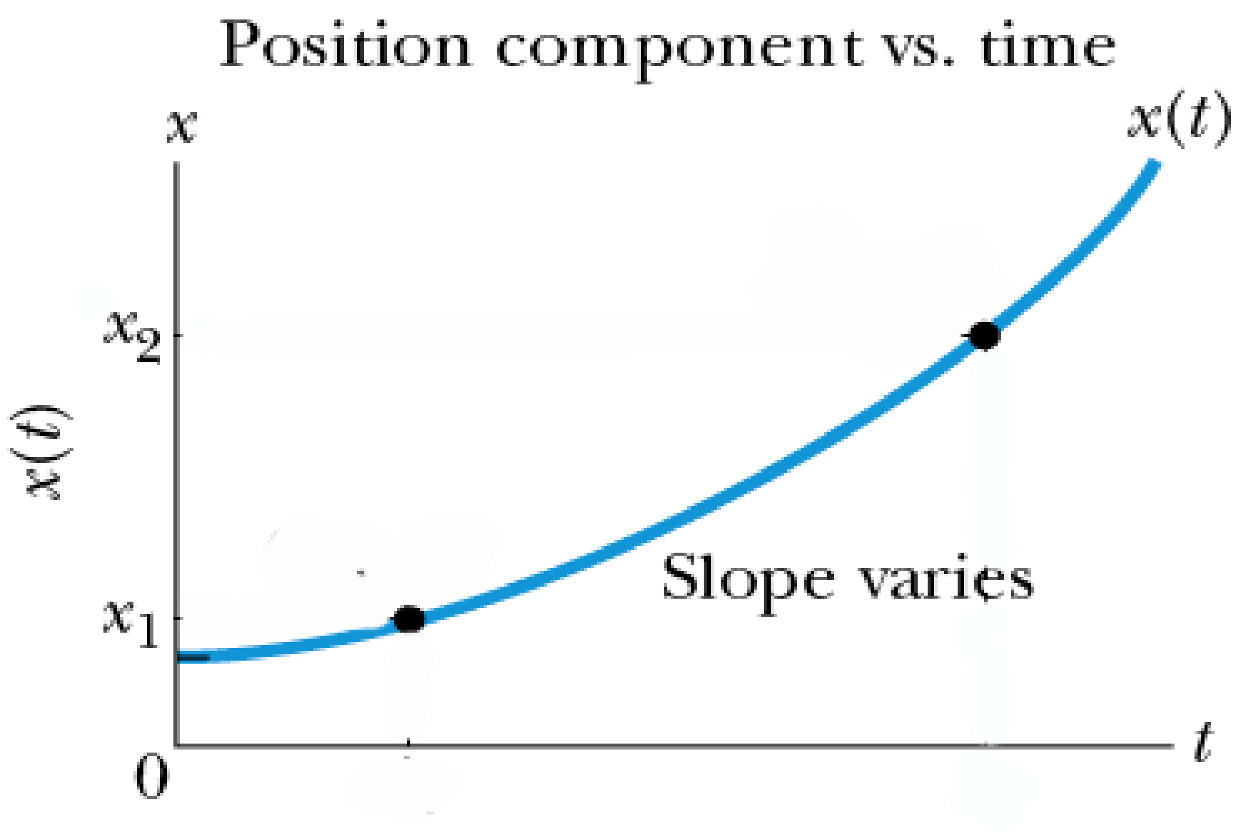
Equations

- Constant Acceleration

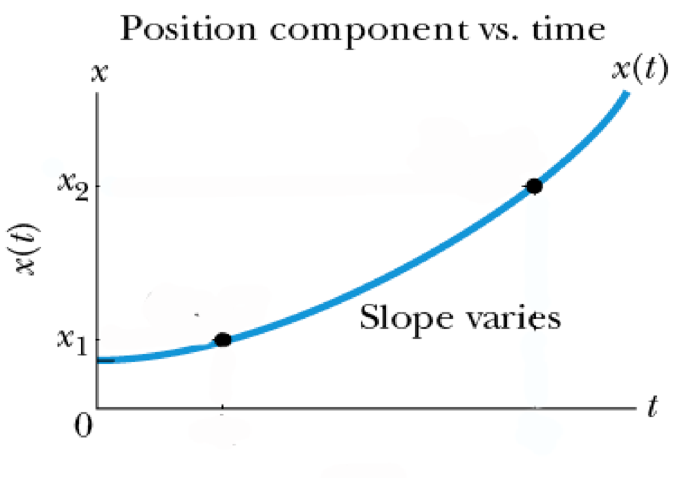
- Changing velocity at a constant rate

- A simplified Kinematic Equation

Importance of the Graph

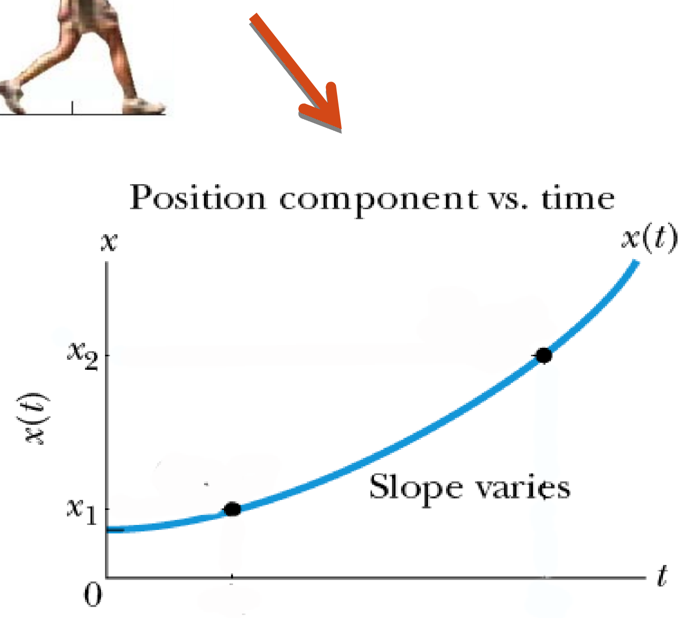


Importance of the Graph



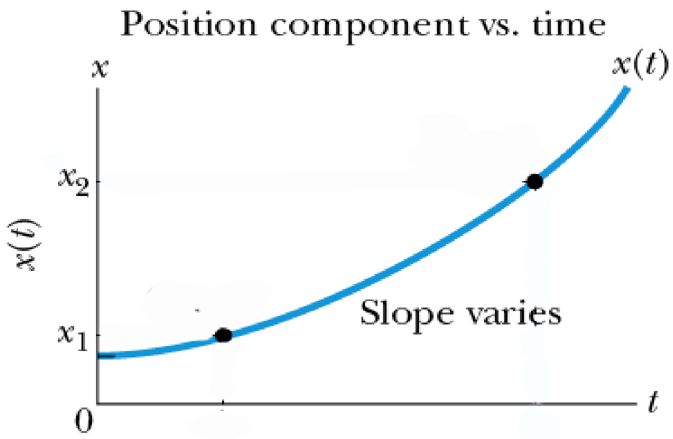
Importance of the Graph

Link between Picture



Importance of the Graph

Link between Picture and Equation



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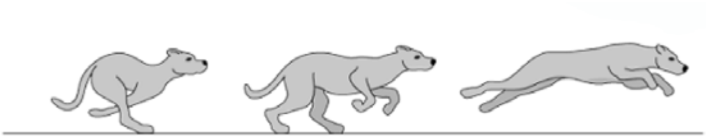
KINEMATICS TEACHING, PART 3

Accelerated Motion



Introduction: During the last block we worked with measuring and representing steady motions involving constant velocities. What about objects that speed up or slow down? For example, suppose a panther that is standing still suddenly sees a rabbit running away from it. The panther starts running as fast as possible to catch it. It is speeding up. Other motions involve slowing down such as a bicycle slowing to a stop or a ball being tossed upward.

- In this session we will start by examining how students can measure the motion of objects that having changing velocities by using the techniques they have already learned. This is a challenge since students might want to start by studying falling motions, but falling motions happen too fast to be observed.

  But without taking measurements, students can look at two kinds of walking motions to help them understand some conceptual ideas about motions that change in a regular manner and erratic motions as well. In addition students can also observe the motion of a marble or small ball rolling down a table that is tilted at a small angle. They can also measure the motion of a ball on a tilted table using the tools they are already familiar with.

In traditional courses the kinematic the equations are derived for the purpose of describing constant accelerations. Students can try to determine whether a ball or marble rolling down a tilted table has a more or less constant acceleration. They can also explore whether or not the acceleration is different when an object rolls down an incline and when it travels up an incline.

Objectives for this Session

A. To help students learn to observe whether or not various fairly slow motions seem to have no velocity change, a steady velocity change, or an erratic velocity change.

B. To help students learn to plot position-time graphs of changing motions and perhaps sketch approximate velocity-time graphs based on the position time graphs.

C. To review the qualitative definition of acceleration as the rate of velocity change and understand why $a \neq 0$ for all motions during times when an object's velocity is changing.

D. To see if the simplified kinematic equations for position (x or y) as a function of time can be used to match data where velocity seems to be changing.

E. To consider whether or not an object's acceleration is approximately constant when it rolls down a titled table and when it rolls up the same table. What happens when the object is changing direction at the top of its roll? Does the acceleration become zero? Why or why not?

WALKING MOTIONS WITH CHANGING VELOCITY

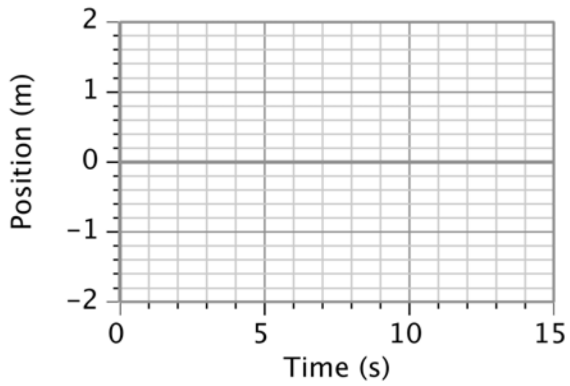
Step 1-Gather What You Need:

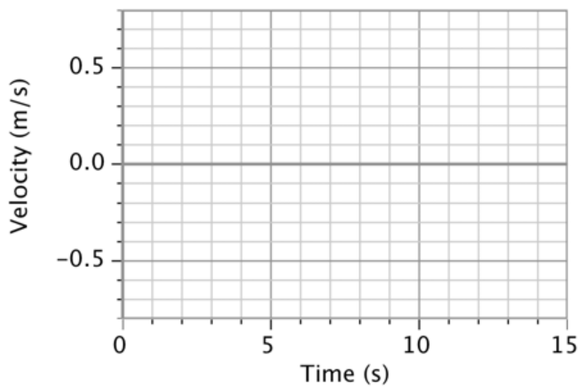
- 1 Number Line (that extends from –2 m to +2 m)
- Basic equipment for measuring length and time (Pendula, Ruler)
- 15 Small Coins (from any country in the world)
- String and a pencil with an eraser
- A marble or a small smooth ball
- A level table with a flat surface and some books to raise one end

Step 2-Make Predictions for Smooth Walking Motions

[a] ***Slow Down Steadily:*** Suppose you are walking very rapidly in the positive direction but as soon you pass the –2 m mark on your number line you slow down steadily so that it takes you exactly 15 seconds to come to a stop at the +2 m mark. Practice doing this and then predict what you think a graph of your position vs. time and your velocity vs. time would look like.

[a] Slowing Down Steadily



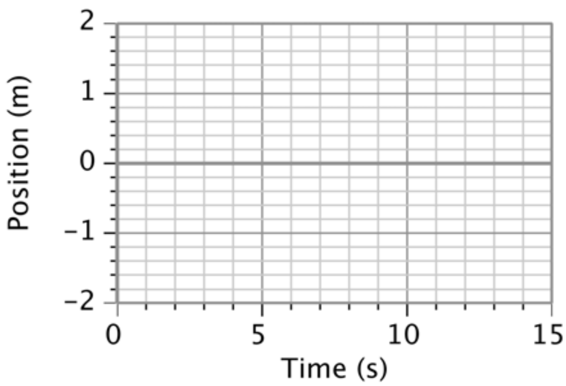


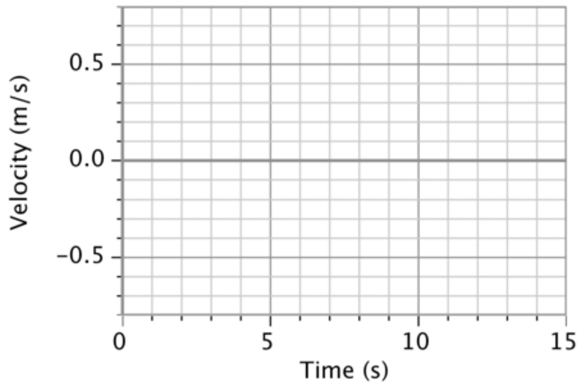
Discussion: Compare your predictions with those of your partners. Then make any changes to your graph to make it more accurate.

Explain the Reasons for your Final Predictions:

[b] ***Speed Up Steadily*****:** Suppose you are standing at +2 m mark on your number line while facing in the negative direction. You speed up steadily so that it takes you exactly 15 seconds to pass at the –2 m mark. Practice doing this and then sketch what you predict a graph of your position vs. time and your velocity vs. time would look like.

[b] Speeding Up Steadily



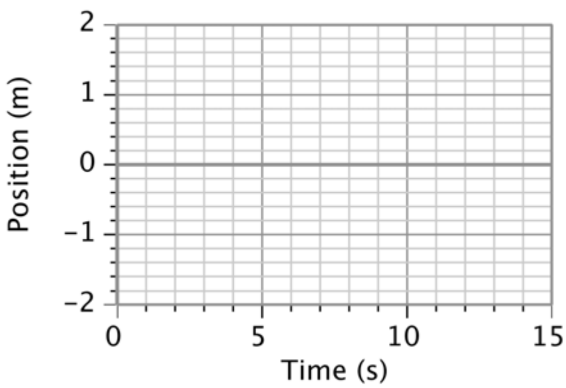


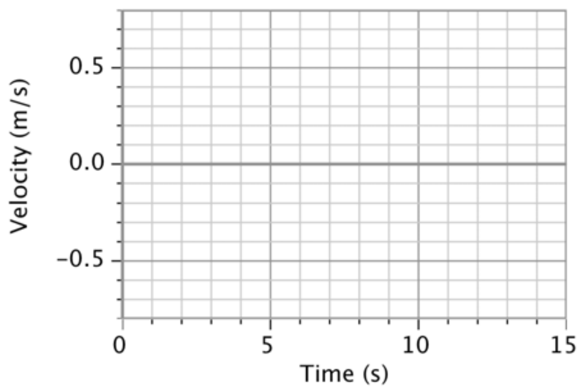
Discussion: Compare your predictions with those of your partners. Then make any changes to your graph to make it more accurate.

Explain the Reasons for your Final Prediction:

[c] ***Slow Down Steadily, Change Direction and then Speed Up Steadily*****:** Suppose you are walking very rapidly in the positive direction. But as soon as you pass the 0 m mark on your number line you slow down steadily so that it takes you exactly 7.5 seconds to come to zero velocity at the +2 m mark. At that instant you change direction then immediately start speeding up steadily. Speed up so that it takes you exactly 7.5 seconds to pass the 0 m mark. Practice doing this and then sketch what you predict a graph of your position vs. time and your velocity vs. time would look like.

[c] Steadily Slowing Down, Changing direction and Speeding Up

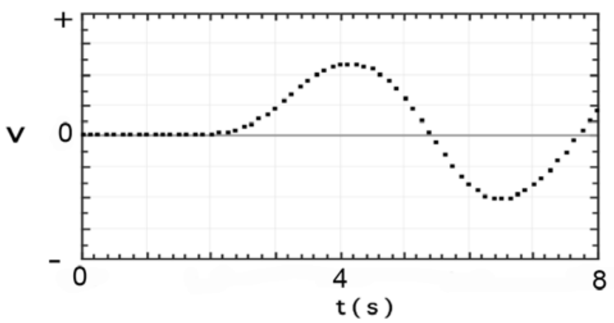




Discussion: Compare your predictions with those of your partners. Then make any changes to your graph to make it more accurate.

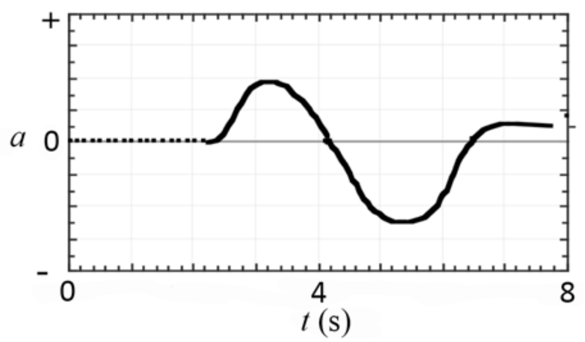
Explain the Reasons for your Final Prediction:

Step 4-Relating a Non-Constant Velocity Graph to a Motion Although motions with constant velocity or with constant acceleration (due to steadily changing velocities) are quite common, some motions do not have constant velocities or accelerations. Consider the velocity-time graph below. Use the box on the right to describe how you would have to walk to make the motions depicted in the graph. Since there are no numbers on the velocity axis, a general description will be fine. But you will need to refer to specific times. Also words like positive and negative directions and speeding up and slowing down will be needed.

Graph 1 	**Description of Walk**:

Step 5-What Does the Shape of the Acceleration Graph Look Like? Francisca, an investigator in another group, tells you that graph 2 below has the right shape to be an acceleration-time graph for the motion. Her Partner, Aziz, argues the graph 2 is not the right shape.

Graph 2



Who is right Francisca or Aziz? Discuss this with your partners and list reasons why graph 2 has the right shape or why graph 2 does not have the right shape. Base your arguments on the concept that acceleration during a small time interval represents the rate of change of velocity.

Reasons the Shape is Right:	**Reasons the Shape is Wrong:**

Discussion: Compare your predictions with those of your partners and then summarize your conclusions.

Step 6-Learn about a Kinematic Equation and Its Graphs: During your theoretical consideration of motion you should have learned that many, but not all, motions involve constant accelerations. If the acceleration of an object that is moving along a line is constant and a coordinate system is chosen, the kinematics equation that can be used to describe its position as time passes is

$$x = \tfrac{1}{2}at^2 + v_0 t + x_0$$

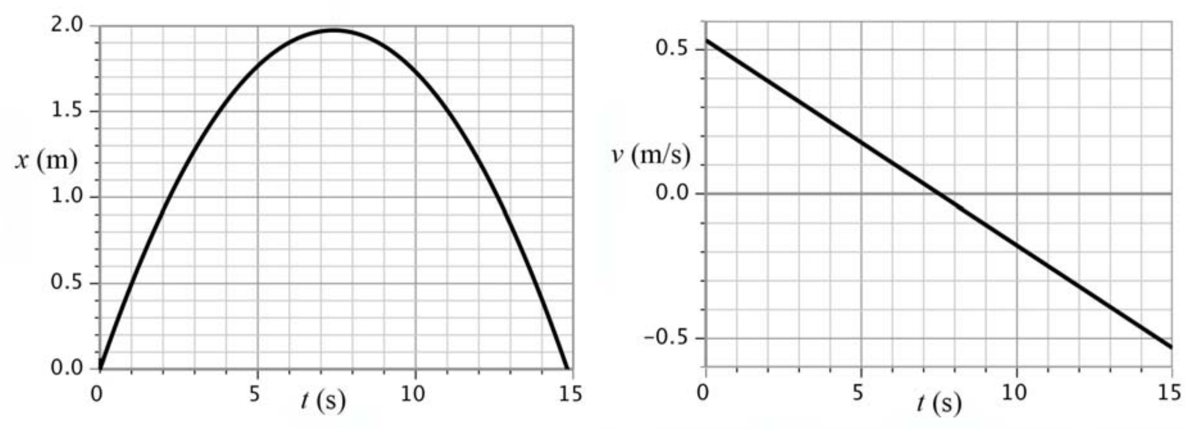
where

x	is the position of an object relative to a chosen origin.
x_0	is the position of the object when the clock started (at $t = 0$)
t	is the time that has passed since the object was at location x_0
a	is the acceleration of the object
v_0	is the velocity of the object when the clock started (at $t = 0$)

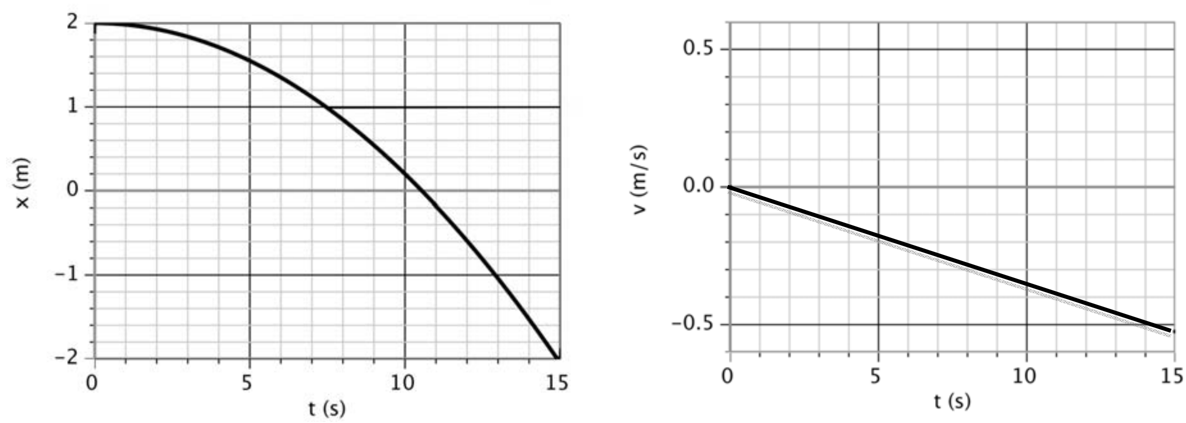
This equation is known as a quadratic or parabolic equation because a graph of x as a function of t has a parabolic shape.

Each pair of graphs shown below represents a different constant acceleration motion.

Motion 1



Motion 2



Step 7–Associate the Idealized Graphs for Motions 1&2 with Your Walking Motions: Examine the graphs of walking motions a, b and c that your created during *Step 2*. Draw lines showing which idealized motion shown above best describes, if at all, each walking motion.

Idealized Motion 1	Walking Motion [a]
Idealized Motion 2	Walking Motion [b]
	Walking Motion [c]

Summarize the evidence that lead to your choices:

Step 8–Set up a Tilted Table to Observe Various Rolling Motions: We would like to have you work with a tilted table and explore whether the rolling motions seem to be constant accelerations. Consult with your partners and figure out how to raise one end of a flat table using books so that its angle is about 1.5°.

Explain what measurements and calculations you and your partner did to have the required angle of tilt. Show the calculations in the space below:

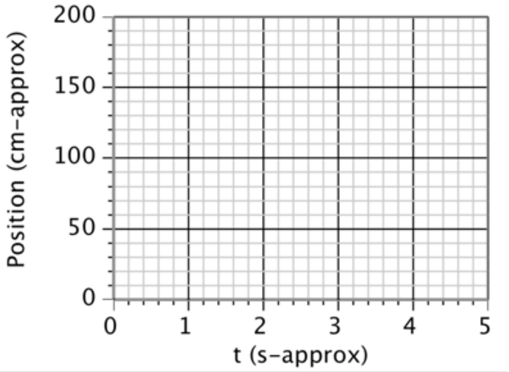
Step 9–Observe up Some Rolling Motions: Roll an object up and down your tilted table and observe what happens. Does the ball seem to speed up and slow down steadily at various times or is it constant or is it erratic? Explain

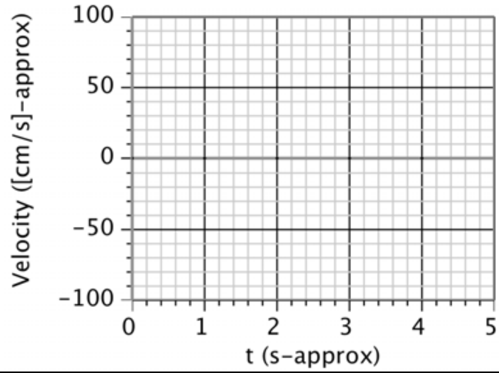
Step 10–Measure Position vs. Time for Your Ball Rolling Up and then Down: Choose an origin near one end of the table and define upward as the positive direction. You may need about 10 coins for this activity. Figure out how to obtain position time data for a marble rolling up and then down the tilted table. Set up a rolling speed that allows you to place coins at 4 or more locations along the table as it rolls upward (or downward). Record your best data in the table below.

DATA FOR MARBLE OR BALL ROLLING UP AND DOWN

t **( )**										
x **( )**										

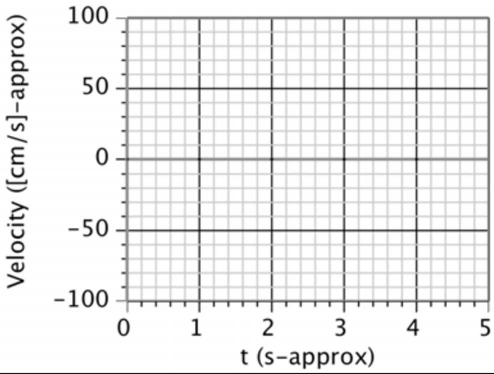
Step 11-Plot Your Data: Plot your position-time data using the graph frame below. You'll have some uncertainties in your data, but do the points seem to lie along a line? If so, estimate the slope of the line and sketch an idealized velocity-time graph below.

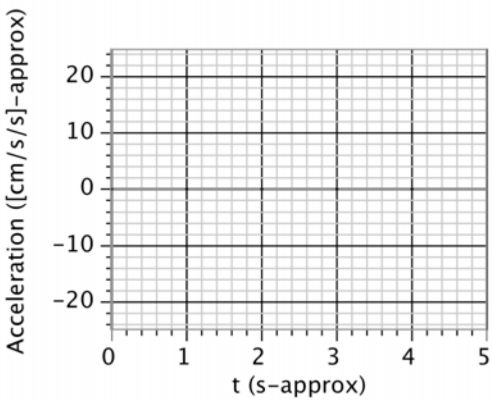




Discussion: Compare your graphs with those of your partners. Then change your graphs to make them more accurate.

Step 12-Sketch an Acceleration Graph for Your Rolling Motion: Copy the sketch you placed in the Step 4 velocity-time graph below. Then use the definition of acceleration as change in velocity near a given point to sketch an idealized acceleration-time graph below.

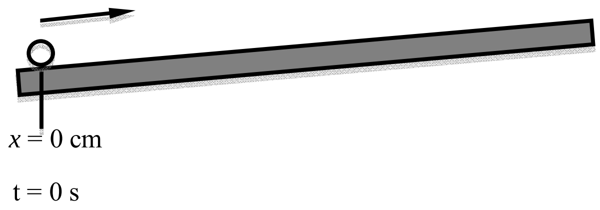




Discussion: Compare your graphs with those of your partners. Then change your graphs to make them more accurate.

Step 13–Reflect on Your Measurements and Graphs of the Up and Down Rolling Motion: Does the motion seem to have a constant acceleration? If so use the kinematic equation presented in *Step 6* to calculate an approximate value for it. Is the acceleration when the ball is rolling up approximately the same as when it is rolling down? Talk with your partners and write down some ideas.

Step 14-Create a Motion Diagram for your Rolling Object: Remember that a motion diagram is like a strobe photo or one-dimensional plot of the motion you are studying. You should draw the location of your object at equal time intervals.



NOTE: When a ball is dropped and falls straight down, it happens so fast that some students believe that it speeds up very quickly to its "natural" falling velocity and then falls at a constant velocity. In our final session we will explore low cost methods for demonstrating that when falling freely a small dense object undergoes a constant acceleration. Based on this assumption, we can then measure gravitational acceleration. This acceleration will be much greater than that of a ball rolling down a tilted table.

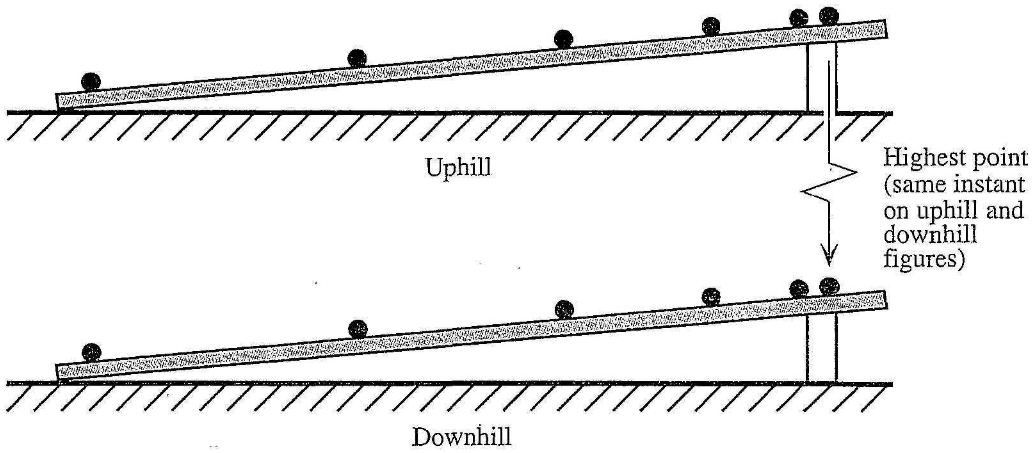
Wrap Up Discussions:

1. Join with the instructors and other workshop participants to describe some of the teaching ideas used in this introductory lesson. Write down some ideas:

2. Join with the instructors and other workshop participants to discuss ways that this lesson could have been improved. Write down some ideas:

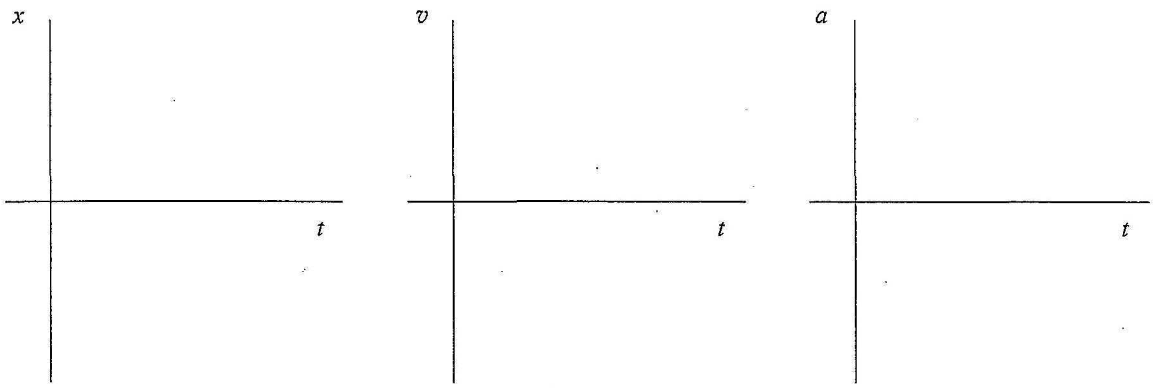
TUTORIALS IN PHYSICS
HOMEWORK, pp 13-14
L.C. McDermott, et. al.
(Prentice Hall, 2002)

1. A ball rolls up, then down an incline. Sketch an *acceleration diagram* for the entire motion. (An *acceleration diagram* is similar to a velocity diagram; however, the vectors on an acceleration diagram represent the *acceleration* rather than the velocity of an object.)

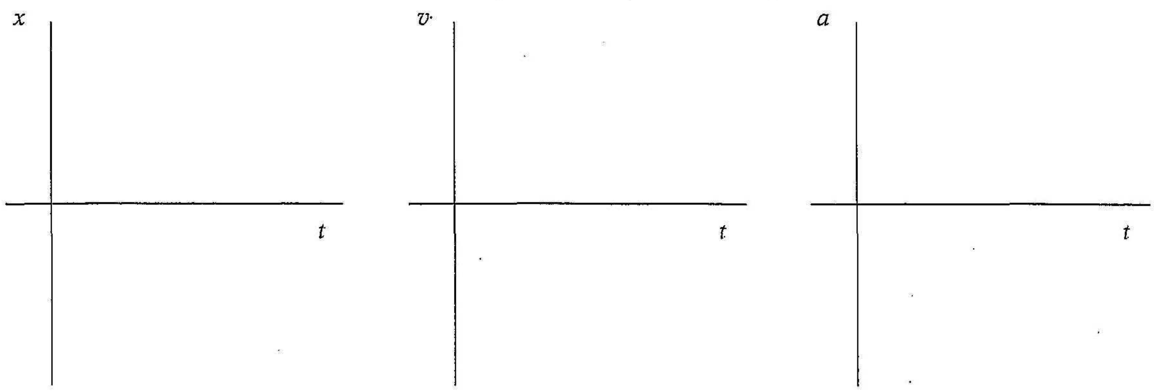


2. Sketch x versus t, v versus t, and a versus t graphs for the entire motion of a ball rolling up and then down an incline.

   a. Use a coordinate system in which the positive x-direction is *down* the track.



   b. Use a coordinate system in which the positive x-direction is *up* the track.



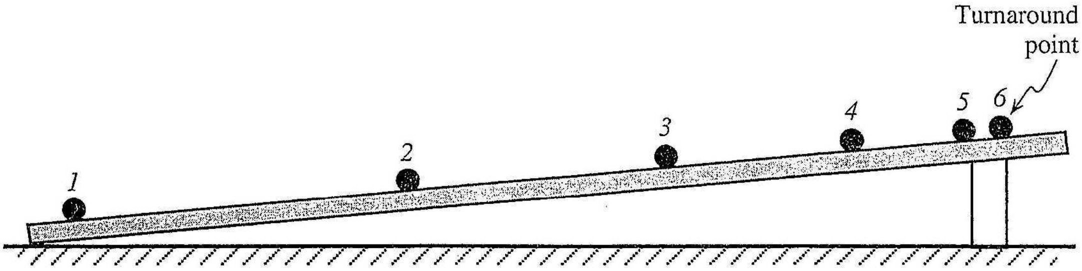
   c. Can an object have a negative acceleration and be speeding up? If so, describe a possible physical situation and a corresponding coordinate system. If not, explain why not.

TUTORIALS IN PHYSICS, pp 11-14
L.C. McDermott, et. al.
(Prentice Hall, 2002)
60 to 90 minutes

ACCELERATION IN ONE DIMENSION

I. Motion with decreasing speed

The diagram below represents a strobe photograph of a ball as it rolls *up* a track. (In a strobe photograph, the position of an object is shown at instants separated by *equal time intervals*.)



A. Draw vectors on your diagram that represent the instantaneous velocity of the ball at each of the labeled locations. If the velocity is zero at any point, indicate that explicitly. Explain why you drew the vectors as you did.

We will call diagrams like the one you drew above *velocity diagrams*. Unless otherwise specified, a velocity diagram shows both the location and the velocity of an object at instants in time that are separated by equal time intervals.

B. In the space at right, compare the velocities at points *1* and *2* by sketching the vectors that represent those velocities. Draw the vectors side-by-side and label them $\vec{v}_1$ and $\vec{v}_2$, respectively.

$\vec{v}_1$, $\vec{v}_2$, and $\Delta\vec{v}$

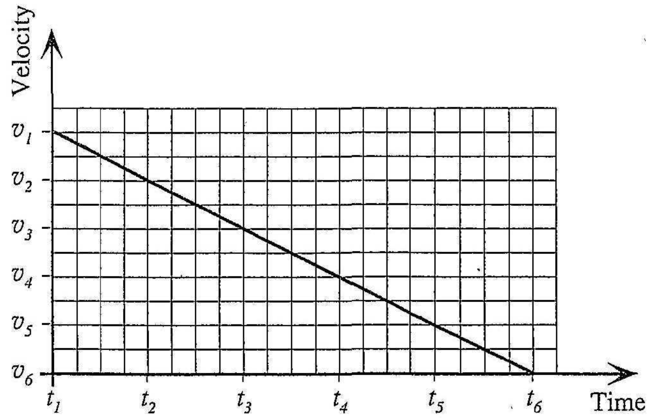
Draw the vector that must be *added* to the velocity at the earlier time to equal the velocity at the later time. Label this vector $\Delta\vec{v}$.

Why is the name *change in velocity* appropriate for this vector?

How does the direction of the change in velocity vector compare to the direction of the velocity vectors?

Would your answer change if you were to select two *different* consecutive points (*e.g.*, points *3* and *4*) while the ball was slowing down? Explain.

How would the magnitude of the change in velocity vector between points *1* and *2* compare to the magnitude of the change in velocity vector between two *different* consecutive points (*e.g.*, points *3* and *4*)? Explain. (You may find it useful to refer to the graph of velocity versus time for the motion.)



Note: The positive direction has been chosen to be *up* the track.

C. Consider the change in velocity vector between two points on the velocity diagram that are not consecutive, *e.g.*, points *1* and *4*.

Is the direction of the change in velocity vector different than it was for consecutive points? Explain.

Is the length of the change in velocity vector different than it was for consecutive points? If so, how many times larger or smaller is it than the corresponding vector for consecutive points? Explain.

D. Use the definition of acceleration to draw a vector in the space at right that represents the acceleration of the ball between points *1* and *2*.

Acceleration vector

How is the direction of the acceleration vector related to the direction of the change in velocity vector? Explain.

E. Does the acceleration change as the ball rolls up the track?
Would the acceleration vector you obtain differ if you were to choose (1) two different successive points on your diagram or (2) two points that are not consecutive? Explain.

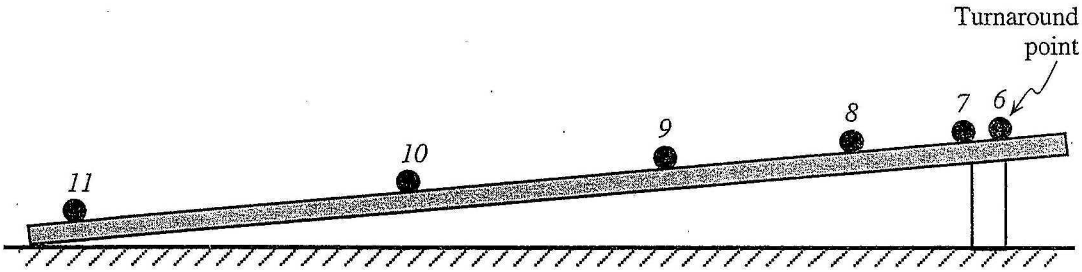
F. Generalize your results thus far to answer the following question:

What is the relationship between the direction of the acceleration and the direction of the velocity for an object that is moving in a straight line and slowing down? Explain.

Describe the direction of the acceleration of a ball that is rolling up a straight incline.

II. Motion with increasing speed

The diagram below represents a strobe photograph of a ball as it rolls *down* the track.



A. Choose two successive points. In the space at right, sketch the velocity vectors corresponding to those points. Draw the vectors side-by-side and label them $\vec{v}_i$ and $\vec{v}_f$, respectively.

$\vec{v}_i$, $\vec{v}_f$, and $\Delta\vec{v}$

Determine the vector that must be added to the velocity at the earlier time to equal the velocity at the later time. Is the name *change in velocity* appropriate for this vector?

How does the direction of the change in velocity vector compare to the direction of the velocity vectors in this case?

Would your answer change if you were to select two *different* points during the time that the ball was speeding up? Explain.

B. In the space at right, draw a vector to represent the acceleration of the ball between the points chosen above.

Acceleration vector

How is the direction of the change in velocity vector related to the direction of the acceleration vector? Explain.

Generalize your results thus far to answer the following question:

What is the relationship between the direction of the acceleration and the direction of the velocity for an object that is moving in a straight line and speeding up? Explain.

Describe the direction of the acceleration of a ball that is rolling down a straight incline.

III. Motion that includes a change in direction

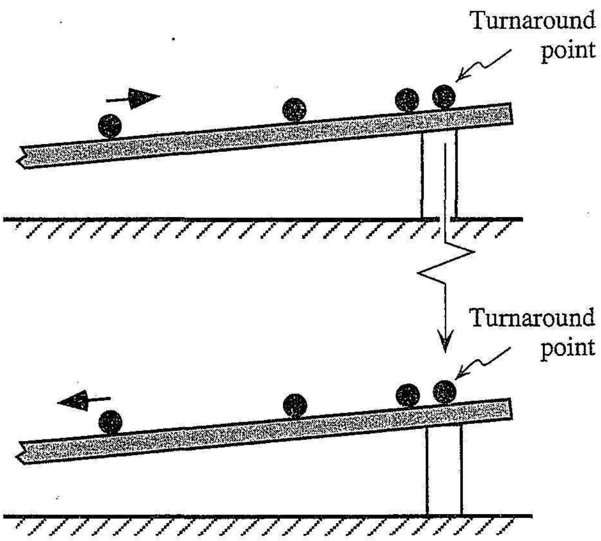
Complete the velocity diagram below for the portion of the motion that includes the turnaround.

A. Choose a point *before* the turnaround and another *after*.

In the space below, draw the velocity vectors and label them $\vec{v}_i$ and $\vec{v}_f$.

Draw the vector that must be added to the velocity at the earlier time to obtain the velocity at the later time.

Is the name *change in velocity* that you used in sections I and II also appropriate for this vector?



B. Suppose that you had chosen the turnaround as one of your points.

What is the velocity at the turnaround point?

Would this choice affect the direction of the change in velocity vector? Explain why or why not.

$\vec{v}_i$, $\vec{v}_f$, and $\Delta\vec{v}$

C. In the space at right, draw a vector that represents the acceleration of the ball between the points you chose in part B above.

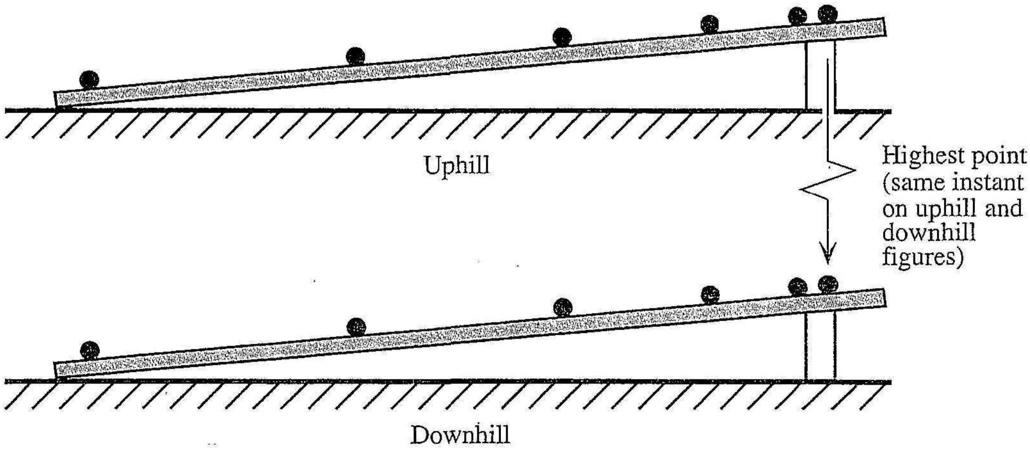
Compare the direction of the acceleration of the ball at the turnaround point to that of the ball as it rolls: (1) up the track and (2) down the track.

Acceleration vector

ACCELERATION IN ONE DIMENSION

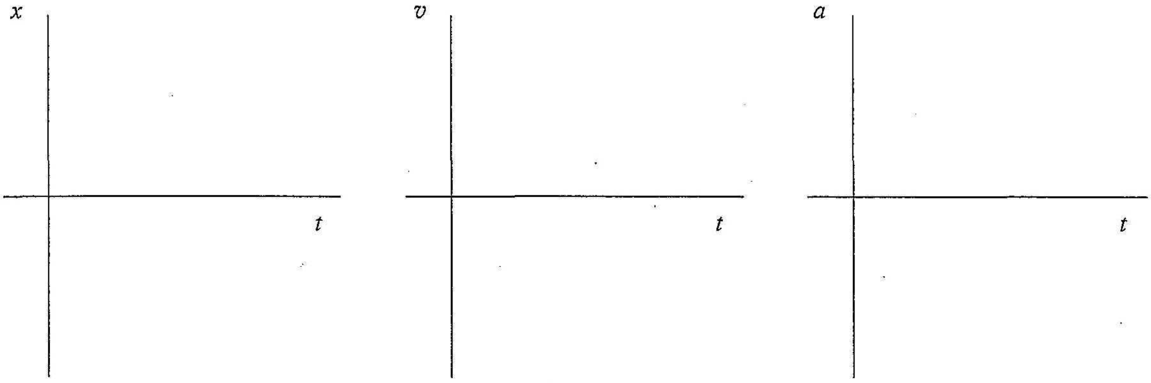
TUTORIALS IN PHYSICS
HOMEWORK, pp 13-14
L.C. McDermott, et. al.
(Prentice Hall, 2002)

1. A ball rolls up, then down an incline. Sketch an *acceleration diagram* for the entire motion. (An *acceleration diagram* is similar to a velocity diagram; however, the vectors on an acceleration diagram represent the *acceleration* rather than the velocity of an object.)

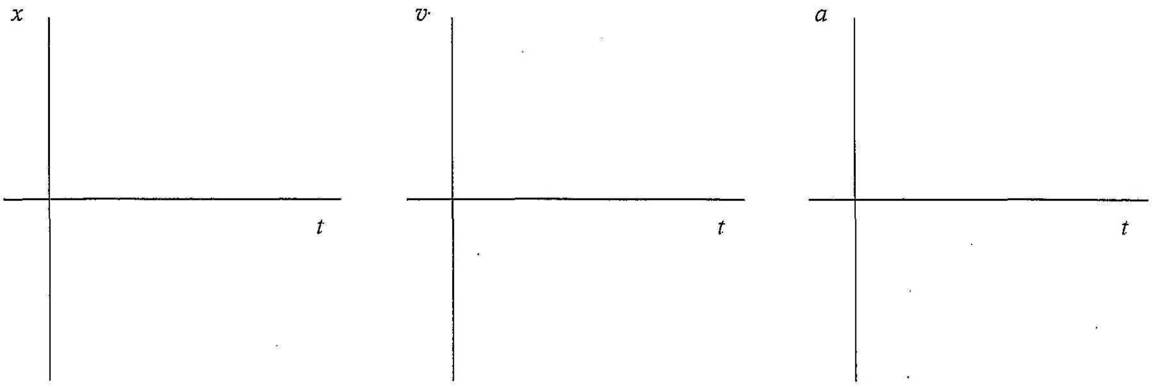


2. Sketch x versus t, v versus t, and a versus t graphs for the entire motion of a ball rolling up and then down an incline.

   a. Use a coordinate system in which the positive x-direction is *down* the track.



   b. Use a coordinate system in which the positive x-direction is *up* the track.



   c. Can an object have a negative acceleration and be speeding up? If so, describe a possible physical situation and a corresponding coordinate system. If not, explain why not.

3. Describe the motion of an object:

   a. for which the direction of the acceleration is the *same as* the direction of motion of the object.

   b. for which the direction of the acceleration is *opposite to* the direction of motion of the object.

   c. for which the change in velocity is zero.

   d. for which the initial velocity is zero but the acceleration is not zero.

4. Two carts roll toward each other on a level table. The vectors represent the velocities of the carts just before and just after they collide.

   a. Draw and label a vector for each cart to represent the *change in velocity* from before to after the collision. Make the magnitude and direction of your vectors consistent with the vectors drawn above.

   b. How does the direction of the average acceleration of cart A compare to the direction of the average acceleration of cart B over the time interval shown? Explain.

   c. For the time interval shown, is the magnitude of the average acceleration of cart A *greater than, less than,* or *equal to* the magnitude of the average acceleration of cart B? Explain.

PHYSWARE
Introduction to Low Cost Kinematics Teaching with Active Learning

KINEMATICS TEACHING, PART 4

Free Fall

Introduction: During the last session we worked with measuring and representing 1D motions with changing velocities. You used a table tilted at a very small angle and measured position and time for a ball that rolls up and down the table. You should have discovered that the acceleration of this motion might be constant for a perfectly round ball rolling on a perfectly flat table.

When a ball is dropped freely and falls straight down, it falls so fast that it is impossible to measure its motion using the basic measuring tools you have developed. We have found that some students believe a dropped ball speeds up very quickly to its "natural" falling velocity and then falls at a constant velocity.

For a teacher using low-cost materials, it is hard to have students prove that objects don't fall at constant velocity. If students have studied up and down motions on a ramp, then one obvious approach is to ask them to look at a vertical ball toss and ask what is happening when the ball is changing direction at the top of the path. The direction change happens so rapidly that some students still imagine a ball rising at constant upward velocity, stopping for awhile at the top of the path, and then speeding up quickly to its natural falling velocity.

In this final session on low cost kinematics, you will use some low cost methods for demonstrating that a small dense object that is falling freely: (1) does not fall at a constant velocity; (2) seems to undergoes a constant acceleration; and (3) falls at an acceleration that has a magnitude of about 9.8 m/s/s (an acceleration which is obviously much greater than that of a ball rolling down a tilted table.)

Recommended Sequence of Activities for Understanding Freefall

A. Ask students to predict what kind of motion an object undergoes when it is dropped and give reasons for their predictions.

B. Have students predict what happens to the time of fall if the distance an object falls doubles with: (1) a constant velocity or (2) a constant acceleration.

C. Have students to consider the "constant velocity" hypothesis and calculate the ratios of dropping heights that would have evenly spaced fall times of 1s, 2s, 3s, 4 s and so on.

D. Have students to consider the "constant acceleration" hypothesis and calculate the ratios of dropping heights would give evenly spaced fall times of 1s, 2s, 3s, 4 s and so on.

E. Ask students to space washers along 3m string so that they can hear that the fall times of the washers are equally spaced. Do the spacings need to be equal (constant velocity hypothesis)? Or do the spacings need to keep increasing (acceleration hypothesis) .

F. Ask students to measure the fall times for fairly long falling distances and do the calculations needed determine an approximate value for free fall acceleration.

> **Note**: To measure freefall times indoors for distances of 5m or less, students may have to resort to using the timing feature on a low cost digital watch and measure the effects of reaction times!

Activity A: *(1) Discuss of Student Ideas About Freefall with Your Partners* – Assume that your students have not worked with an inclined ramp. What ideas do you predict they will have about the nature of free fall? Write down some ideas.

(2) Discuss of Student Ideas About Freefall with Other Groups – Write down any new ideas.

Activities B-E: Read through Activity 4.8 (Equal Time, Equal Distance) and its Teacher's Notes(pp. 73-75) from J. Mader & M. Winn, *Teaching Physics for the First Time* (AAPT Press, College Park MD, 2008). < http://www.aapt.org/Store/products.cfm>.

Summarize what you hear if:

(a) You use the constant velocity hypothesis (equal spacing):

(b) You use a constant acceleration hypothesis (carefully calculated increasing spacing):

Activity F: Read and do the activities listed in pages 1-10 from:

P. Jolly, V.B. Bhatia & M. Verma, *Developing a Research-Based Laboratory Curriculum for Introductory Physics* (INFOSYS-IAPT Workshop on Innovative Methods of Teaching Physics, University of Delhi, 28 Dec 2004 to 02 Jan 2005)

When you finish or time runs out for the session return to this page and participate in a wrap up discussion.

Wrap Up Discussions:

1. If your group was able to determine a value for the gravitational acceleration "g" write down your results and describe some of the difficulties your group had.

2. Discuss your findings with the other groups and write down suggestions for improving free fall measurements.

CONTINUED ON NEXT PAGE →

3. Join the instructors and other workshop participants to describe some of the teaching ideas used in this introductory lesson. Write down some ideas:

4. Join the instructors and other workshop participants to discuss ways that this lesson could have been improved. Write down some ideas:

4.8. Equal Time, Equal Distance[6]
(Demonstration or Mini-Lab)

This activity can be done as a teacher demonstration with the apparatus made ahead of time or as a mini-lab. Instructions for using the activity as a mini-lab are included at the end of the demonstration section.

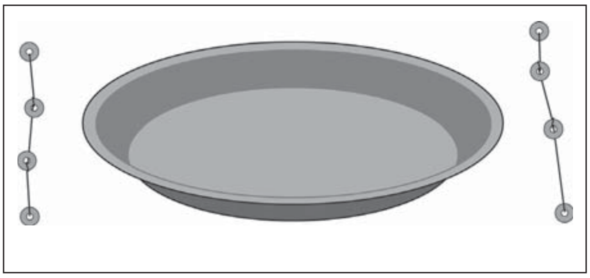


Fig. 4.11. Metal pan and washers for free-fall demonstration

Description

The accelerated motion of free fall is demonstrated with washers tied to a string and dropped onto a metal pan. One string has washers tied in five equal distances, and the other string has the washers tied in equal time increments.

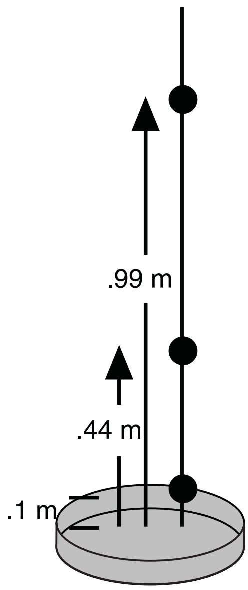


Fig. 4.12. Equal time string

Discussion

Students often have difficulty understanding the accelerated motion of free fall. With this demonstration they can clearly hear the difference in the beat between the equal distance string (irregular, accelerating beat) and the equal time string (regular beat). The students should then be encouraged to analyze the difference between the two strings. For the equal time string, it is easily observed that the washers travel farther in a given period of time at the top of the string than they do at the bottom of the string (Fig. 4.12). A more detailed analysis would measure and analyze the distance traveled during each time increment. The calculations all center on the kinematics equation:

$$d = v_i t = \frac{1}{2}at^2$$

where the initial velocity is zero.

Hints for This Demonstration

The strings and washers tend to tangle very easily. Store them wrapped on a piece of sturdy cardboard and handle them one at a time.

How To Present This Demonstration

Place a metal pan upside down on the floor so it makes the maximum amount of noise. Have a student stand on a ladder or sturdy lab table and drop the washers onto the pan. It is best to start with a washer resting on the pan. Drop the string of equally spaced washers first. The students can clearly hear that the time intervals are different. Then drop "equal time" string so that students can hear that the time intervals are the same. To increase the class involvement, repeat this several times and ask the class to clap the rhythm of the washers hitting the pan for both situations.

Equipment Needed for This Demonstration

- A metal pan or a metal wastebasket
- Equal distance string—a 2.8-m string with washers attached at one end and in five equal increments
- Equal time string—washers tied at 0 m, 0.11 m, 0.44 m, 0.99 m, 1.76 m, 2.75 m from one end; this is based on a 0.15-s time interval

Other Ideas

- Make really long string and washer combinations and drop them off the football stadium or bandstand onto a pan. An option that the students will love is to replace the washers with water balloons. The sound is much more dramatic.
- This activity can be done as a mini-lab by having the students calculate and create their own equal time, equal distance drop. A possible write-up for this demo is given in the following mini-lab.

Pie Pan Kinematics
Mini-Lab

Problem

How would you place four lead sinkers on a string so that they hit a pie pan at equal time intervals?

Materials

3 m string, 4 sinkers, pie pan, meterstick

Procedure

1. Tape one end of the string to the pie pan.
2. Attach a sinker on the string 2.7 m from the pan.
3. Use the kinematic equations to determine the other three sinker locations.
4. Show all calculations in a lab book.
5. Describe each step of your calculation.
6. Attach remaining sinkers.
7. Drop the string and see if you succeeded.

Equal Time, Equal Distance (Teacher's Notes)

Additional Suggestions for Presenting This Demo

Drop the string of equally spaced washers from as high as possible onto a metal wastebasket (or the pizza pan or metal pie pan). If the metal wastebasket is turned upside down, the sound will be enhanced.

Have the students describe the sound.

The intervals should be unequal, becoming shorter.

Then drop the second string with washers closer together on the bottom from the same height as the first.

Have the students describe the sound.

The interval between the clicks should now be equal.

Look at both strings again and explain these intervals.

The farther a washer falls the more it is accelerated. Because the washers at the top of the string have fallen farther, they are moving faster as they land.

The rate of acceleration is a constant rate found to be 9.8 m (about 32 ft) per second for each second the object is falling. This means that a falling object is moving 9.8 m/s faster at the end of each second than it was moving just one second earlier.

If the object is dropped from rest so that the initial velocity is zero, the equation to determine velocity is

$$v = at$$

where a = (acceleration of gravity = 9.8 m/s^2) and t = (time is in seconds)

Acceleration due to gravity is symbolized by g.

What is the final velocity of an acorn that takes 2 s to fall from the top of a tree?

HINT: Remember acceleration due to gravity means that every second the velocity changes by 9.8 m/s. (Assume no loss due to air friction.)

$$v_f = gt$$

$$v_f = 9.8 \text{ m/s}^2(2 \text{ s})$$

$$v_f = 19.6 \text{ m/s}$$

4.9. Acceleration of a Dropped Ball

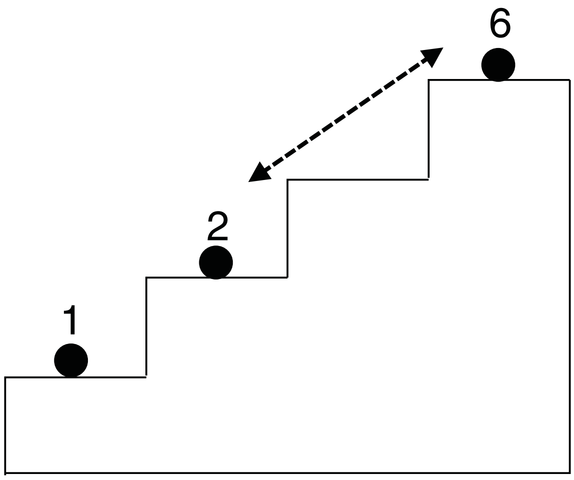


Fig.

Problem

How is the time of free fall related to the distance fallen? How is the final speed in free fall related to the acceleration?

Materials

Tennis ball, meterstick, stopwatch

Procedure

1. Drop the tennis ball from the edge of the bleachers for at least six different heights.

   HINT: Measure the height of the first drop and then add or subtract for each successive drop height by either measuring and counting the stairs or using a meterstick. To ensure a measurable time difference, vary the distances dropped by at least one-half meter.

2. Time how long it takes from the release to the impact of the ball with the ground. At least three trials with relatively close times are required for an average time.
3. Record your information in a data table.
4. Calculate the final velocity of the ball. Assume uniform acceleration and that the ball doesn't reach terminal velocity.
5. Make a graph of final velocity vs. time. Determine the slope for the graph.

Table 4.6. Data table for final speed

Total distance fallen (m)	Times (s)			Average time (s)	Average velocity (m/s)	Final velocity (m/s)

Table 4.7. Data table for calculating acceleration

Calculated acceleration $a = v_f/t$ (m/s²)	$\lvert a_{gravity} - a_{calculated} \rvert$ (m/s²)	% error

Summing Up

1. How does the final velocity change with each change in time? Why does this change occur?

2. What is the slope of the final velocity vs. time graph? How does it compare to the acceleration due to gravity?

Acceleration of a Dropped Ball (Teacher's Notes)

Teaching Strategies

This is a high interest activity that will allow out-of-class exposure for your course. It is best if this can be done out of doors on stadium bleachers, but bleachers in a gym area work as well. Remind students to drop, not throw, the ball and to average at least three trials per height for more accurate results. Use tennis or racket balls as they do not reach terminal velocity as quickly as Ping-Pong or smaller balls do. If students carefully measure the height from which the ball is dropped and time it accurately, they will find that the calculated slope of the velocity vs. time graph is within 10% of the acceleration due to gravity. If the errors are significant, have students determine reaction times and correct the drop times. Round all calculations to the nearest tenth.

Table 4.8. Sample data of carefully timed ball drops

Total distance fallen (m)	Times (s)			Average time (s)	Average velocity (m/s)	Final velocity (m/s)
5	1.05	1.08	1.03	1.05	4.8	9.6
6	1.14	1.04	1.15	1.13	5.3	10.6
7	1.20	1.25	1.24	1.23	5.7	11.4
8	1.29	1.34	1.33	1.32	6.1	12.2
9	1.40	1.48	1.45	1.44	6.3	12.6
10	1.47	1.55	1.52	1.52	6.6	13.2

Table 4.9. Acceleration

Calculated acceleration $a = v_f/t$ (m/s^2)	$\lvert a_{gravity} - a_{calculated} \rvert$ (m/s^2)	% error
9.1	0.7	7
9.4	0.4	4
9.3	0.5	5
9.2	0.6	6
8.8	1.0	10
8.7	1.1	11

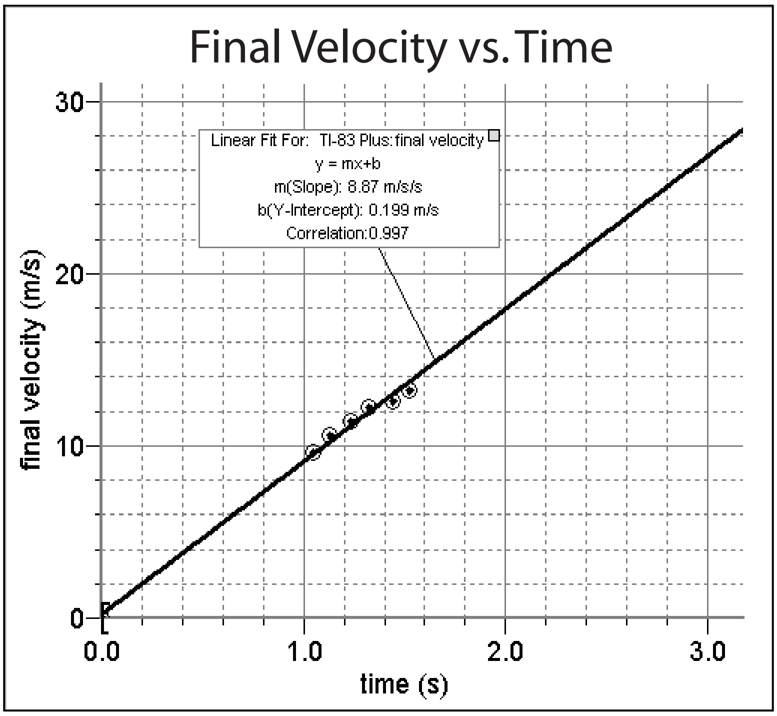


Fig. 4.14. Slope of Velocity vs. Time graph

Summing Up

1. How does the final velocity change with each change in time? Why does this change occur?

   Ans: The final speed increases with greater distances dropped. The larger the distance the smaller the increment of increase becomes, perhaps due to more drag and because the ball is approaching terminal velocity.

2. What is the slope of the final velocity vs. time graph? How does it compare to the acceleration due to gravity?

   Ans: The calculated slope of the final velocity time graph is 8.8 m/s^2, which is roughly a 10% error. Individually the errors are less.

PHYSWARE
A Collaborative Workshop on Low-Cost Equipment and Appropriate Technologies that Promote Undergraduate Level, Hands-on Physics Education throughout the Developing World

The Abdus Salam International Centre for Theoretical Physics, Trieste, Italy 16 to 27 February 2009

DEVELOPING A RESEARCH-BASED LABORATORY CURRICULUM FOR COLLEGE PHYSICS

Pratibha Jolly

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SAMPLE MATERIAL
from
UNIT: TEST A HYPOTHESIS
UNIT: MEASUREMENT
UNIT: ERRORS OF MEASUREMENT

Developed in collaboration by
Pratibha Jolly, Mallika Verma and Vishnu B Bhatia

Workshop Session
Developing Procedural and Conceptual Knowledge in the Laboratory
16-27 February 2008

MODEL OF INSTRUCTION

Level 1: Eliciting Novice Performance.

(i) ***Pre-laboratory Questionnaire*:**
This includes questions to elicit students' understanding about design of experiment, concepts of procedure and the physics of the problem.

(ii) ***Laboratory Activity*:**
The worksheet provides the theoretical background and a guided exposure to the laboratory task. Inasmuch as many critical decisions about data collection are left to the student, the activity provides an opportunity for spontaneous play with the measurement process. Learning by hit and trial is a crucial in situations that are little understood.

Level 2: Facilitating Transition.

(iii) ***Data Assessment*:**
The instrument helps the student to subdivide the whole task into subtasks and assess each step using a pertinent set of criterions. By comparing her data with that of an imaginary experimenter, the student is sensitized to deficiencies in her performance.

(iv) ***Bridging Exercises*:**
The worksheet consists of a careful sequence of concept and data probes. Simple hands-on exercises and thought experiments provide analogous learning for each subtask and help the student make informed choices about the measurement parameters.

Level 3: Generating Expertise.

(v) ***Laboratory Activity*:**
With negligible guidance, the new worksheet seeks a fresh hands-on performance on either the same task, suitably enhanced and extended, or a related application. The assessment of this activity determines the gain in learning and the success of the instructional process.

Depending on individual requirement, the student may be required to cycle through the earlier steps (i) to (iv) in this instructional cycle at her own pace.

Pre-laboratory Questionnaire

You are given a one rupee coin. In this activity, you are required to

- drop the coin from rest at height *y* and find the time *t* it takes to hit the floor.
- determine the relation between the height *y* and the time of fall *t*.
- determine the value of acceleration due to gravity *g*.

1. Design the experiment

1.1. Briefly describe the complete procedure you will adopt to make the measurements necessary to obtain the desired relation between height of fall *y* and the time *t*.

1.2. List the equipment/ apparatus you would require to perform this experiment.

1.3. Figure 1.1 shows three different ways of placing the coin and measuring its height before it is dropped. Place a tick mark to indicate the correct arrangement.

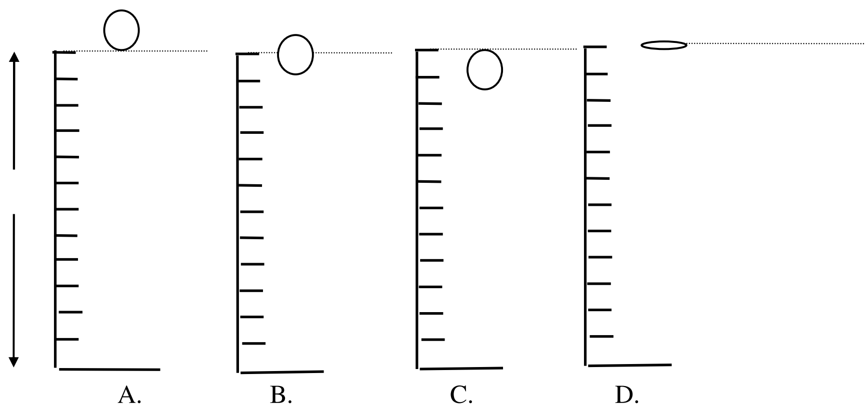


Figure 1.1

(a) Justify your answer.

1.4. Suggest the values of height *y* you will choose to drop the coin from.

1.5. Make a table (label all columns) to indicate how you will record your observations.

1.6. How many times will you drop the coin from the same height to measure the time taken?

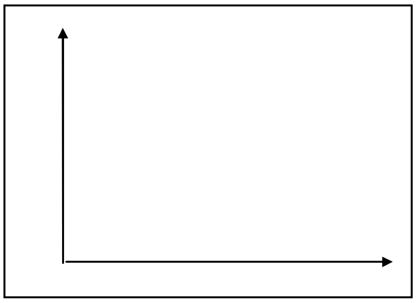
1.7. Once you have the observations, describe how you would proceed to analyze the data to discover the relationship between the height from which the coin is dropped and the time it takes to hit the floor.

1.8. If you would like to draw a graph, what would you plot along the

(a) x-axis

(b) y-axis

1.9. What do you expect the graph between y and t to look like? Draw a rough sketch in the space provided below.



1.10. A coin is held at rest and then dropped from a height of 1 m.

(a) According to you, how much time will it take to hit the ground?

(b) Explain how you got your answer.

1.11. If you were to drop a five rupee, a one rupee and a fifty paise coin (listed in order of decreasing weights) simultaneously from the same height,

(a) which coin will hit the ground first?

(b) Explain your answer.

1.12. If you drop a one rupee coin face down or edge down,
(a) will it make a difference in the time taken to hit the ground?

(b) Explain your answer.

1.13. A one rupee coin and a cardboard disk of the same radius are dropped together from a height of 1 m.
(a) Will there be a difference in the time each takes to reach the ground?
(b) If so, to what factors would you attribute the difference?

1.14. Anju dropped a one rupee coin (A) and a cardboard disk (B) of same radius from a height of 1 m and then from a height of 2 m.
(a) According to you, which one of the following observations could be correct:
(i) Time taken by A = Time taken by B at 1 m
(ii) Time taken by A = Time taken by B at 2 m
(iii) Time taken by A > Time taken by B at any height
(iv) Time taken by A < Time taken by B at any height
(v) Difference in time taken by A and B increases as height is increased.
(vi) Difference in time taken by A and B decreases as height is increased.

(b) Justify your answer.

Laboratory Activity

You are given a one rupee coin. In this activity, you are required to

- drop the coin from rest at height *y* and find the time *t* it takes to hit the floor.
- determine the relation between the height *y* and the time of fall *t*.
- determine the value of acceleration due to gravity *g*.

1. Procedure

This is a straightforward experiment. A measuring tape has been stuck on the wall to help you measure the height. Figure 1.2 shows how you should place the coin before dropping it.

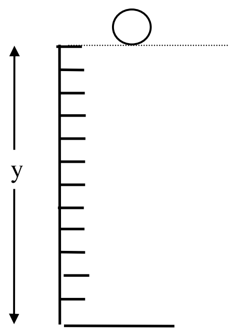


Figure 1: Measuring the height of coin at rest at height y above the ground

- The height *y* is measured as the distance from the lower end of the coin to the floor.
- Use a digital stopwatch to measure the time taken.
- We suggest you drop the coin from at least 1.5 m above the ground.
- It takes some skill to drop the coin so that it falls vertically downward without turning around.
- Start the stopwatch as soon as you release the coin and stop it as soon as it lands on the floor.
- Practice doing all this before you get down to taking actual observations.
- When you are ready, take the final set of observations and record these.

2. Observations

You will have to decide the

- values of height *y* at which the investigation is to be carried out.
- number of times you want to repeat the measurement of *t* for each *y*.
- Record your observations in Table 1 which has four columns. The first three columns are labeled as shown in the sample table given below. For the moment, leave column 4 blank. This is for later calculations. (In case you want to take more than one set of observations, use extra sheets to tabulate the data according to the above format.)

TABLE 1

Column 1 S. No.	Column 2 Height y (cm)	Column 3 Time of fall t (s)	Column 4

3. Test the hypothesis

3.1. If you want to see graphically how the time of fall *t* varies with height *y* from which the coin is dropped, what will you plot on the

(a) x-axis

(b) y-axis

Hypothesis

The time taken for the coin dropped, from a position at rest, vertically downwards is straightforwardly given by $y = \frac{1}{2}gt^2$. Thus, the time of fall $t = \sqrt{\frac{2y}{g}}$. The presumption is that the coin has no other motion and experiences no drag or drift due to air.

To test the validity of this hypothesis,

- Label column 4 "$\sqrt{y}$ (cm)$^{-1/2}$". Calculate $\sqrt{y}$ for each value of y and fill the column.
- Take a graph sheet and plot column 4 along the x-axis and column 3 along the y-axis.
- You will have to choose an appropriate scale.

3.2. Looking at the graph you have drawn, what can you say about the validity of the hypothesis?

3.3.

(a) From the graph, calculate the value of acceleration due to gravity and write down its value:

g = ________ cm s^{-2}

(b) How does your value compare with the expected value of g? Calculate the value of the percent fractional error

$$\frac{\Delta g}{g_{expected}} = \left| \frac{g_{experimental} - g_{expected}}{g_{expected}} \right| \times 100 \quad =$$

4. Reliability of data

4.1. Comment on any special difficulties you faced while performing this experiment.

4.2. State any precautions you took while performing the experiment.

4.3. According to you, what is the accuracy of your observations?

Assessment Examinations: Action Research Kit

Web Address:

http://physics.dickinson.edu/~wp_web/wp_resources/wp_assessment.html

Select the examination you want to down load and when asked to log on, enter the following info:

User Name: WPInstructor
Password: GimmeStuff

What is Action Research? Action Research is a method for assessing the effectiveness of your teaching without undertaking a formal publishible educational research project. This set of assessment examinations will enable you to undertake action research on a number of topics using a series of multiple choice conceptual assessments.

The Workshop Physics Action Research Kit (ARK) consists of conceptual and attitudinal surveys appropriate for use with students who are using Workshop Physics materials. These surveys will help you assess whether your Workshop Physics students have learned the critical concepts and improved their attitudes towards science and learning physics.

The Kit Contains the Following Examinations:
The Mathematical Modeling Conceptual Evaluation (MMCE)
The Vector Evaluation Test (VET)
The Force-Motion Concept Evaluation (FMCE)
The Heat and Temperature Concept Evaluation (HCTE)
The Electric Circuits Concept Evaluation (ECCE)
The Maryland Physics Expectations Survey (MPEX)

Suggestions for administering ARK Examinations: Most of these assessment examinations should be administered on a pre and post test basis so that you can assess gains in student learning or changes in student attitudes and expectations over the span of time covered by your course.

Pre-test: The pre-test should be given as early in the class as possible, preferably on the first day. As with any pre-instruction test the students are not expected to know the material. You might want to reassure them that a poor score will not affect their grade. It is vital that you collect all copies of the exams from the students so they will not use it to study for later exams. It is also important that you not return the exams to the students after you grade them. It is often reassuring to students if you offer to go over the results of a pre test personally.

Post-test: There are two opinions on when to administer post-tests. One opinion is that it is best to incorporate the post-test in an exam so that the students have maximum motivation to answer the questions. Another says that this may give an artificially high score as the students will have crammed for the test and that it is best to "surprise" the students with the post-test, which can still be graded for motivation. It is up to you which to choose. Once again, it is vital that you collect all copies of the exams from the students so they will not give it to students who you might administer the exam to in the future. It is also important that you not return the exams to the students after you grade them. It is often helpful if you offer to go over the results of a post test personally with any student who is interested.

REMINDER: THESE ASSESSMENT EXAMINATIONS AND THE ANSWER KEYS SHOULD NEVER BE GIVEN TO STUDENTS TO KEEP.

The Mathematical Modeling Conceptual Evaluation (MMCE)
by Ron Thornton with help from Priscilla Laws and Pat Cooney
This survey focuses on representation translation skills between equations (parameters in linear and quadratic equations) and graphs; and between descriptions of physical systems and graphs of their rates of change. Nominally the survey has 37 items (25 functional dependence and 12 rates of change), but 10 of the items are matrix-like and require 5 answers each. These items would have to be rearranged to permit machine grading with Scantron sheets.
For more information, contact Priscilla Laws
* Printable version
* Answer key

The Force-Motion Concept Evaluation (FMCE)
by Ron Thornton and David Sokoloff
A survey containing 47 items in a multiple-choice multiple-response format. This covers a wider variety of topics than the FCI, including many more questions on kinematics. Machine gradeable on a Scantron sheet except for one item, which requests a written response. An Excel Template to help you analyze this assessment is available at the University of Maine Physics Education Research website .
For more information, see R.K. Thornton and D.R. Sokoloff, "Assessing student learning of Newton's laws: The Force and Motion Conceptual Evaluation," Am. J. Phys. 66(4), 228-351 (1998) or contact Ron Thornton or David Sokoloff.
* Printable version
* Answer key

The Heat and Temperature Concept Evaluation (HCTE)
by Ron Thornton and David Sokoloff
A 28 item survey on concepts of heat, temperature, and heat flow. Should take about 30-40 minutes to complete. All but one of the items are machine gradeable. One item requires drawing a graph and writing a sentence. For more information on the survey, contact Ron Thornton or David Sokoloff.
An Excel Template to help you analyze this assessment is available at the University of Maine Physics Education Research website .
* Printable version
* Answer key

The Electric Circuits Concept Evaluation (ECCE)
by David Sokoloff
A 45 item multiple-choice survey probing student understanding of direct and alternating current circuits. Some items include capacitors and inductors. Machine gradeable using 10-item Scantron sheets. Some items request explanations. Should take about one hour to complete.
For more information, contact David Sokoloff.
An Excel Template to help you analyze this assessment is available at the University of Maine Physics Education Research website .
* Printable version
* Answer key

The Maryland Physics Expectations Survey (MPEX)
by E. F. Redish, R. N. Steinberg, and J. M. Saul
A 34-item Likert scale (5-point agree-disagree) survey probing student expectations about the nature of learning in a physics class. Most items fall into 5 clusters: independence/authority, concepts/formulas, coherence/pieces, reality link, and math link. Should take about 20-30 minutes to complete. A spreadsheet for the construction of favorable/unfavorable response diagrams is included. An Excel Template to help you analyze this assessment is available at the University of Maine Physics Education Research website .
For more information on MPEX, see E. F. Redish, J. M. Saul, and R. N. Steinberg, "Student Expectations In Introductory Physics," Am. J. Phys. 66 212-224 (1998) or check the University of Maryland website.

- Printable version

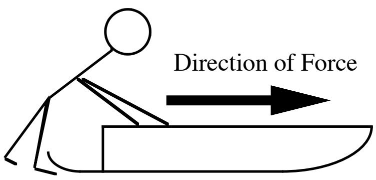
The Vector Evaluation Test (VET)
by Ron Thornton
A 31 item multiple-choice and short-answer survey testing vector analysis skills including addition and subtraction, component analysis, and comparing magnitudes. Not machine gradeable. Should take about 1/2 hour to complete.
For more information, contact Ron Thornton
* Printable version
* Answer key

Force and Motion Conceptual Evaluation

Directions: Answer questions 1-47 in spaces on the answer sheet. Be sure your name is on the answer sheet. Answer question 46a also on the answer sheet. Hand in the questions and the answer sheet.

A sled on ice moves in the ways described in questions 1-7 below. *Friction is so small that it can be ignored.* A person wearing spiked shoes standing on the ice can apply a force to the sled and push it along the ice. Choose the one force (**A** through **G**) which would **keep the sled moving** as described in each statement below.

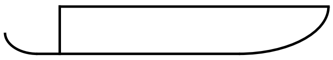
You may use a choice more than once or not at all but choose only one answer for each blank. If you think that none is correct, answer choice **J**.



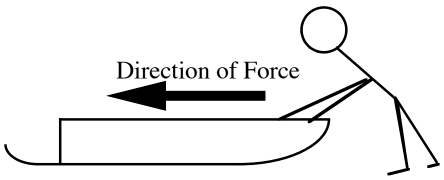
A. The force is toward the **right** and is **increasing** in strength (magnitude).

B. The force is toward the **right** and is of **constant** strength (magnitude).

C. The force is toward the **right** and is **decreasing** in strength (magnitude).



D. No applied force is needed



E. The force is toward the **left** and is **decreasing** in strength (magnitude).

F. The force is toward the **left** and is of **constant** strength (magnitude).

G. The force is toward the **left** and is **increasing** in strength (magnitude).

______1. Which force would keep the sled moving toward the right and speeding up at a steady rate (constant acceleration)?

______2. Which force would keep the sled moving toward the right at a steady (constant) velocity?

______3. The sled is moving toward the right. Which force would slow it down at a steady rate (constant acceleration)?

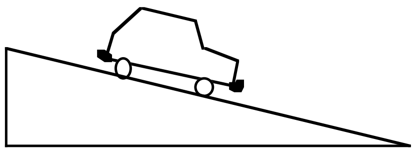
______4. Which force would keep the sled moving toward the left and speeding up at a steady rate (constant acceleration)?

______5. The sled was started from rest and pushed until it reached a steady (constant) velocity toward the right. Which force would keep the sled moving at this velocity?

______6. The sled is slowing down at a steady rate and has an acceleration to the right. Which force would account for this motion?

______7. The sled is moving toward the left. Which force would slow it down at a steady rate (constant acceleration)?

Questions 8-10 refer to a toy car which is given a quick push so that it rolls up an inclined ramp. After it is released, it rolls up, reaches its highest point and rolls back down again. *Friction is so small it can be ignored.*



Use one of the following choices (**A** through **G**) to indicate the **net force** acting on the car for each of the cases described below. Answer choice **J** if you think that none is correct.

(A) Net **constant** force **down** ramp
(B) Net **increasing** force **down** ramp
(C) Net **decreasing** force **down** ramp
(D) Net force zero
(E) Net **constant** force **up** ramp
(F) Net **increasing** force **up** ramp
(G) Net **decreasing** force **up** ramp

_______8. The car is moving up the ramp after it is released.

_______9. The car is at its highest point.

_______10. The car is moving down the ramp.

Questions 11-13 refer to a coin which is tossed straight up into the air. After it is released it moves upward, reaches its highest point and falls back down again. Use one of the following choices (**A** through **G**) to indicate the force acting on the coin for each of the cases described below. Answer choice **J** if you think that none is correct. **Ignore any effects of air resistance.**

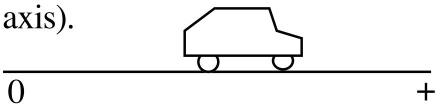
A. The force is **down** and constant.
B. The force is **down** and increasing
C. The force is **down** and decreasing
D. The force is zero.
E. The force is **up** and constant.
F. The force is **up** and increasing
G. The force is **up** and decreasing

_______11. The coin is moving upward after it is released.

_______12. The coin is at its highest point.

_______13. The coin is moving downward.

Questions 14-21 refer to a toy car which can move to the right or left along a horizontal line (the positive part of the distance axis).



Assume that friction is so small that it can be ignored.

A force is applied to the car. Choose the one force graph (**A** through **H**) for each statement below which could allow the described motion of the car to continue.

You may use a choice more than once or not at all. If you think that none is correct, answer choice **J**.

__14. The car moves toward the right (away from the origin) with a steady (constant) velocity.

__15. The car is at rest.

__16. The car moves toward the right and is speeding up at a steady rate (constant acceleration).

__17. The car moves toward the left (toward the origin) with a steady (constant) velocity.

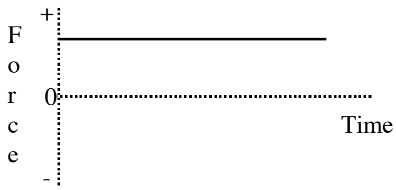
__18. The car moves toward the right and is slowing down at a steady rate (constant acceleration).

__19. The car moves toward the left and is speeding up at a steady rate (constant acceleration).

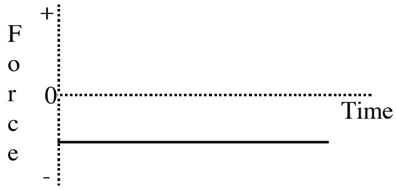
__20. The car moves toward the right, speeds up and then slows down.

__21. The car was pushed toward the right and then released. Which graph describes the force after the car is released.

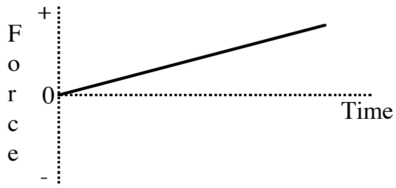
A



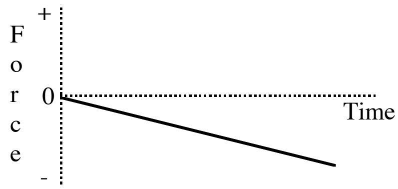
B



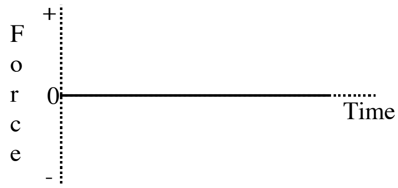
C



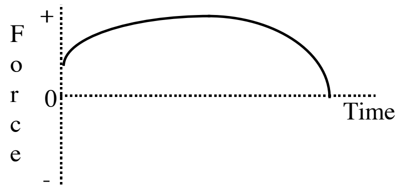
D



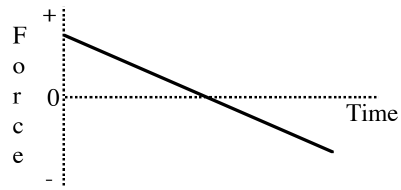
E



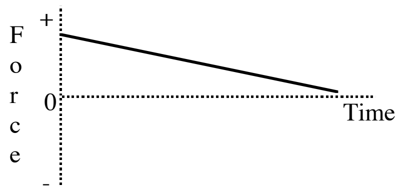
F



G

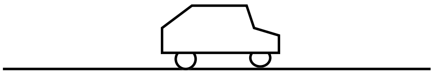


H



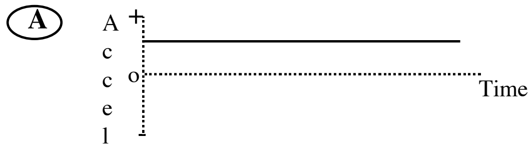
J None of these graphs is correct.

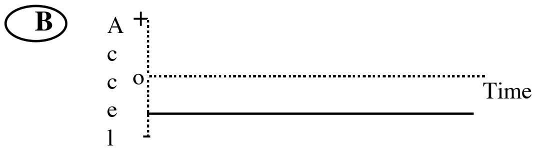
Questions 22-26 refer to a toy car which can move to the right or left on a horizontal surface along a straight line (the + distance axis). The positive direction is to the right.

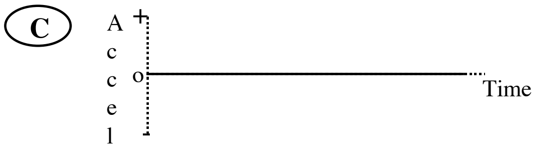


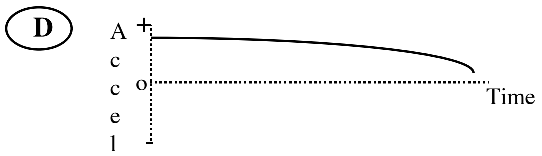
Different motions of the car are described below. Choose the letter (**A** to **G**) of the **acceleration-time** graph which corresponds to the motion of the car described in each statement.

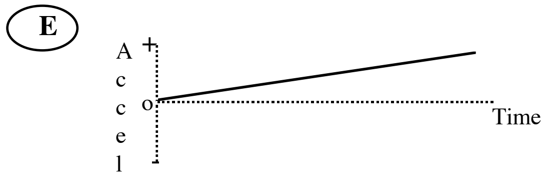
You may use a choice more than once or not at all. If you think that none is correct, answer choice **J**.

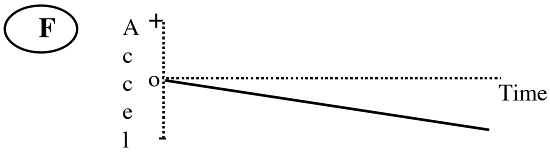


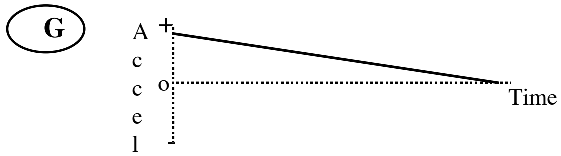












J None of these graphs is correct.

_____22. The car moves toward the right (away from the origin), speeding up at a steady rate.
_____23. The car moves toward the right, slowing down at a steady rate.
_____24. The car moves toward the left (toward the origin) at a constant velocity.
_____25. The car moves toward the left, speeding up at a steady rate.
_____26. The car moves toward the right at a constant velocity.

Questions 27-29 refer to a coin which is tossed straight up into the air. After it is released it moves upward, reaches its highest point and falls back down again. Use one of the following choices (**A** through **G**) to indicate the acceleration of the coin during each of the stages of the coin's motion described below. Take **up** to be the **positive** direction. Answer choice **J** if you think that none is correct.

- **A.** The acceleration is in the negative direction and constant.
- **B.** The acceleration is in the negative direction and increasing
- **C.** The acceleration is in the negative direction and decreasing
- **D.** The acceleration is zero.
- **E.** The acceleration is in the positive direction and constant.
- **F.** The acceleration is in the positive direction and increasing
- **G.** The acceleration is in the positive direction and decreasing

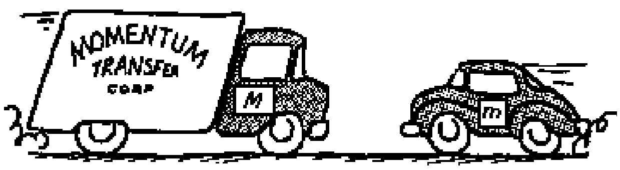
___27. The coin is moving upward after it is released.
___28. The coin is at its highest point.

___29. The coin is moving downward.

Questions 30-34 refer to collisions between a car and trucks. For each description of a collision (30-34) below, choose the one answer from the possibilities **A** though **J** that best describes the forces between the car and the truck.

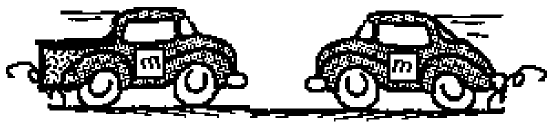
A. The truck exerts a greater amount of force on the car than the car exerts on the truck.
B. The car exerts a greater amount of force on the truck than the truck exerts on the car.
C. Neither exerts a force on the other; the car gets smashed simply because it is in the way of the truck.
D. The truck exerts a force on the car but the car doesn't exert a force on the truck.
E. The truck exerts the same amount of force on the car as the car exerts on the truck.
F. Not enough information is given to pick one of the answers above.
J. None of the answers above describes the situation correctly.

*In questions 30 through 32 the truck is **much heavier** than the car .*



______30. They are both moving at the same speed when they collide. Which choice describes the forces?
______31. The car is moving much faster than the heavier truck when they collide. Which choice describes the forces?
______32. The heavier truck is standing still when the car hits it. Which choice describes the forces?

*In questions 33 and 34 the truck is a small pickup and is the **same weight** as the car.*



______33. Both the truck and the car are moving at the same speed when they collide. Which choice describes the forces?
______34. The truck is standing still when the car hits it. Which choice describes the forces?

Questions 35-38 refer to a large truck which breaks down out on the road and receives a push back to town by a small compact car.

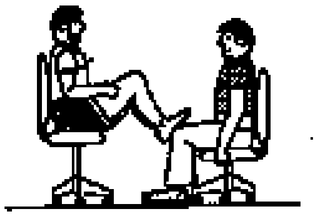
Pick one of the choices **A** through **J** below which correctly describes the forces between the car and the truck for each of the descriptions (35-38).

A. The force of the car pushing against the truck is equal to that of the truck pushing back against the car.
B. The force of the car pushing against the truck is less than that of the truck pushing back against the car.
C. The force of the car pushing against the truck is greater than that of the truck pushing back against the car.
D. The car's engine is running so it applies a force as it pushes against the truck, but the truck's engine isn't running so it can't push back with a force against the car.
E. Neither the car nor the truck exert any force on each other. The truck is pushed forward simply because it is in the way of the car.
J. None of these descriptions is correct.

______35. The car is pushing on the truck, but not hard enough to make the truck move.
______36. The car, still pushing the truck, is **speeding up** to get to cruising speed.
______37. The car, still pushing the truck, is at cruising speed and continues to travel at the **same speed**.

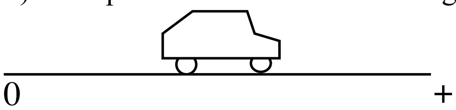
_____38. The car, still pushing the truck, is at cruising speed when the truck puts on its brakes and causes the car to **slow down**.

____39. Two students sit in identical office chairs facing each other. Bob has a mass of 95 kg, while Jim has a mass of 77 kg. Bob places his bare feet on Jim's knees, as shown to the right. Bob then suddenly pushes outward with his feet, causing both chairs to move. In this situation, while Bob's feet are in contact with Jim's knees,

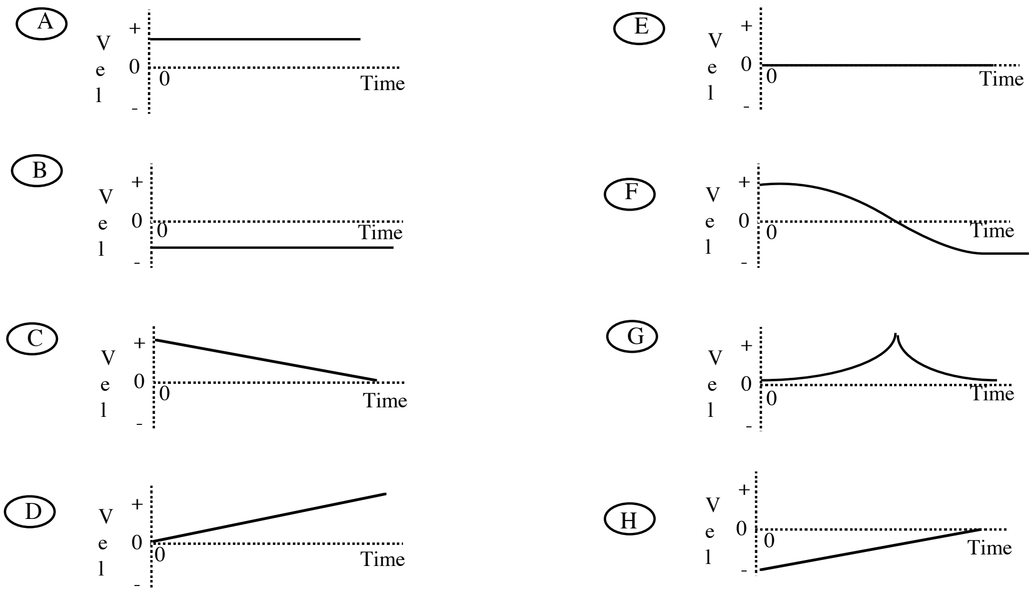


- **A**. Neither student exerts a force on the other.
- **B**. Bob exerts a force on Jim, but Jim doesn't exert any force on Bob.
- **C**. Each student exerts a force on the other, but Jim exerts the larger force.
- **D**. Each student exerts a force on the other, but Bob exerts the larger force.
- **E**. Each student exerts the same amount of force on the other.
- **J**. None of these answers is correct.

Questions 40-43 refer to a toy car which can move to the right or left along a horizontal line (the positive portion of the distance axis). The positive direction is to the right.



Choose the correct velocity-time graph (**A - G**) for each of the following questions. You may use a graph more than once or not at all. If you think that none is correct, answer choice **J**.



(J) None of these graphs is correct.

___40. Which velocity graph shows the car moving toward the right (away from the origin) at a steady (constant) velocity?

___41. Which velocity graph shows the car reversing direction?

___42. Which velocity graph shows the car moving toward the left (toward the origin) at a steady (constant) velocity?

___43. Which velocity graph shows the car increasing its *speed* at a steady (constant) rate?

A sled is pulled up to the top of a hill. The sketch above indicates the shape of the hill. At the top of the hill the sled is released from rest and allowed to coast down the hill. At the bottom of the hill the sled has a speed v and a kinetic energy E (the energy due to the sled's motion). Answer the following questions. ***In every case friction and air resistance are so small they can be ignored.***

_____44. The sled is pulled up a **steeper** hill of the **same** height as the hill described above. How will the velocity of the sled at the bottom of the hill (after it has slid down) compare to that of the sled at the bottom of the original hill? Choose the best answer below.

A. The speed at the bottom is greater for the steeper hill.
B. The speed at the bottom is the same for both hills.
C. The speed at the bottom is greater for the original hill because the sled travels further.
D. There is not enough information given to say which speed at the bottom is faster.
J. None of these descriptions is correct.

_____45. Compare the kinetic energy (energy of motion) of the sled at the bottom for the original hill and the steeper hill in the previous problem. Choose the best answer below.

A. The kinetic energy of the sled at the bottom is greater for the steeper hill.
B. The kinetic energy of the sled at the bottom is the same for both hills.
C. The kinetic energy at the bottom is greater for the original hill.
D. There is not enough information given to say which kinetic energy is greater.
J. None of these descriptions is correct.

_____46. The sled is pulled up a **higher** hill that is **less** steep than the original hill described before question 44. How does the speed of the sled at the bottom of the hill (after it has slid down) compare to that of the sled at the bottom of the original hill?

A. The speed at the bottom is greater for the higher but less steep hill than for the original.
B. The speed at the bottom is the same for both hills.
C. The speed at the bottom is greater for the original hill.
D. There is not enough information given to say which speed at the bottom is faster.
J. None of these descriptions is correct.

46a. Describe in words your reasoning in reaching your answer to question 46. (**Answer on the answer sheet** and use as much space as you need)

_____47. For the higher hill that is less steep, how does the kinetic energy of the sled at the bottom of the hill after it has slid down compare to that of the original hill?

A. The kinetic energy of the sled at the bottom is greater for the higher but less steep hill.
B. The kinetic energy of the sled at the bottom is the same for both hills.
C. The kinetic energy at the bottom is greater for the original hill.
D. There is not enough information given to say which kinetic energy is greater.
J. None of these descriptions is correct.

PHYSWARE
A Collaborative Workshop on Low-Cost Equipment and Appropriate Technologies that Promote Undergraduate Level, Hands-on Physics Education throughout the Developing World

The Abdus Salam International Centre for Theoretical Physics, Trieste, Italy 16 to 27 February 2009

DEVELOPING A RESEARCH-BASED LABORATORY CURRICULUM FOR COLLEGE PHYSICS

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SAMPLE MATERIAL
from
UNIT: TEST A HYPOTHESIS
UNIT: MEASUREMENT
UNIT: ERRORS OF MEASUREMENT

Developed in collaboration by
Pratibha Jolly, Mallika Verma and Vishnu B Bhatia

Workshop Session
Developing Procedural and Conceptual Knowledge in the Laboratory
16-27 February 2008

MODEL OF INSTRUCTION

Level 1: Eliciting Novice Performance.

(i) ***Pre-laboratory Questionnaire*:**
This includes questions to elicit students' understanding about design of experiment, concepts of procedure and the physics of the problem.

(ii) ***Laboratory Activity*:**
The worksheet provides the theoretical background and a guided exposure to the laboratory task. Inasmuch as many critical decisions about data collection are left to the student, the activity provides an opportunity for spontaneous play with the measurement process. Learning by hit and trial is a crucial in situations that are little understood.

Level 2: Facilitating Transition.

(iii) ***Data Assessment*:**
The instrument helps the student to subdivide the whole task into subtasks and assess each step using a pertinent set of criterions. By comparing her data with that of an imaginary experimenter, the student is sensitized to deficiencies in her performance.

(iv) ***Bridging Exercises*:**
The worksheet consists of a careful sequence of concept and data probes. Simple hands-on exercises and thought experiments provide analogous learning for each subtask and help the student make informed choices about the measurement parameters.

Level 3: Generating Expertise.

(v) ***Laboratory Activity*:**
With negligible guidance, the new worksheet seeks a fresh hands-on performance on either the same task, suitably enhanced and extended, or a related application. The assessment of this activity determines the gain in learning and the success of the instructional process.

Depending on individual requirement, the student may be required to cycle through the earlier steps (i) to (iv) in this instructional cycle at her own pace.

Pre-laboratory Questionnaire

You are given a one rupee coin. In this activity, you are required to

- drop the coin from rest at height y and find the time t it takes to hit the floor.
- determine the relation between the height y and the time of fall t.
- determine the value of acceleration due to gravity g.

1. Design the experiment

1.1. Briefly describe the complete procedure you will adopt to make the measurements necessary to obtain the desired relation between height of fall y and the time t.

1.2. List the equipment/ apparatus you would require to perform this experiment.

1.3. Figure 1.1 shows three different ways of placing the coin and measuring its height before it is dropped. Place a tick mark to indicate the correct arrangement.

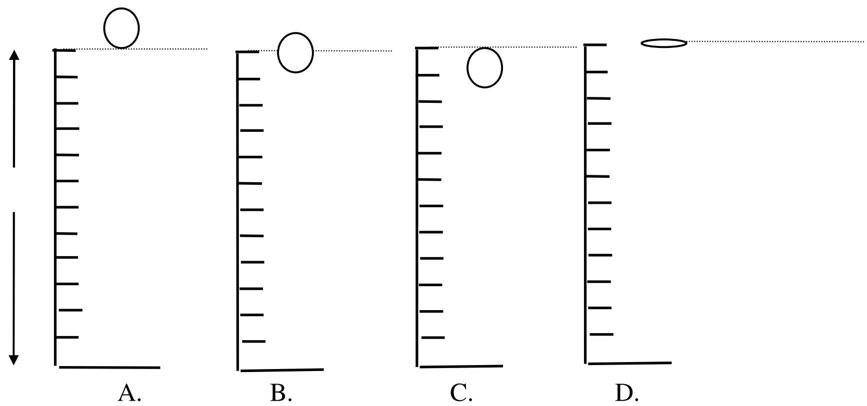


Figure 1.1

(a) Justify your answer.

1.4. Suggest the values of height *y* you will choose to drop the coin from.

1.5. Make a table (label all columns) to indicate how you will record your observations.

1.6. How many times will you drop the coin from the same height to measure the time taken?

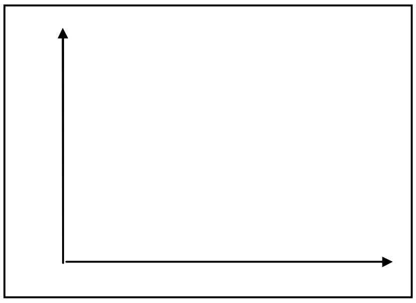
1.7. Once you have the observations, describe how you would proceed to analyze the data to discover the relationship between the height from which the coin is dropped and the time it takes to hit the floor.

1.8. If you would like to draw a graph, what would you plot along the

(a) x-axis

(b) y-axis

1.9. What do you expect the graph between *y* and *t* to look like? Draw a rough sketch in the space provided below.



1.10. A coin is held at rest and then dropped from a height of 1 m.

(a) According to you, how much time will it take to hit the ground?

(b) Explain how you got your answer.

1.11. If you were to drop a five rupee, a one rupee and a fifty paise coin (listed in order of decreasing weights) simultaneously from the same height,

(a) which coin will hit the ground first?

(b) Explain your answer.

1.12. If you drop a one rupee coin face down or edge down,
   (a) will it make a difference in the time taken to hit the ground?

   (b) Explain your answer.

1.13. A one rupee coin and a cardboard disk of the same radius are dropped together from a height of 1 m.
   (a) Will there be a difference in the time each takes to reach the ground?
   (b) If so, to what factors would you attribute the difference?

1.14. Anju dropped a one rupee coin (A) and a cardboard disk (B) of same radius from a height of 1 m and then from a height of 2 m.
   (a) According to you, which one of the following observations could be correct:
      (i) Time taken by A = Time taken by B at 1 m
      (ii) Time taken by A = Time taken by B at 2 m
      (iii) Time taken by A > Time taken by B at any height
      (iv) Time taken by A < Time taken by B at any height
      (v) Difference in time taken by A and B increases as height is increased.
      (vi) Difference in time taken by A and B decreases as height is increased.

   (b) Justify your answer.

Laboratory Activity

You are given a one rupee coin. In this activity, you are required to

- drop the coin from rest at height *y* and find the time *t* it takes to hit the floor.
- determine the relation between the height *y* and the time of fall *t*.
- determine the value of acceleration due to gravity *g*.

1. Procedure

This is a straightforward experiment. A measuring tape has been stuck on the wall to help you measure the height. Figure 1.2 shows how you should place the coin before dropping it.

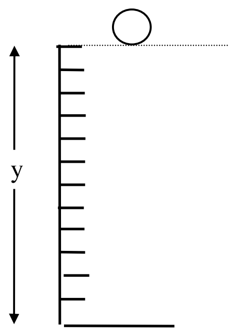


Figure 1: Measuring the height of coin at rest at height y above the ground

- The height *y* is measured as the distance from the lower end of the coin to the floor.
- Use a digital stopwatch to measure the time taken.
- We suggest you drop the coin from at least 1.5 m above the ground.
- It takes some skill to drop the coin so that it falls vertically downward without turning around.
- Start the stopwatch as soon as you release the coin and stop it as soon as it lands on the floor.
- Practice doing all this before you get down to taking actual observations.
- When you are ready, take the final set of observations and record these.

2. Observations

You will have to decide the

- values of height *y* at which the investigation is to be carried out.
- number of times you want to repeat the measurement of *t* for each *y*.
- Record your observations in Table 1 which has four columns. The first three columns are labeled as shown in the sample table given below. For the moment, leave column 4 blank. This is for later calculations. (In case you want to take more than one set of observations, use extra sheets to tabulate the data according to the above format.)

TABLE 1

Column 1 S. No.	Column 2 Height y (cm)	Column 3 Time of fall t (s)	Column 4

3. Test the hypothesis

3.1. If you want to see graphically how the time of fall t varies with height y from which the coin is dropped, what will you plot on the

(a) x-axis

(b) y-axis

Hypothesis

The time taken for the coin dropped, from a position at rest, vertically downwards is straightforwardly given by $y = \frac{1}{2}gt^2$. Thus, the time of fall $t = \sqrt{\frac{2y}{g}}$. The presumption is that the coin has no other motion and experiences no drag or drift due to air.

To test the validity of this hypothesis,

- Label column 4 "$\sqrt{y}$ (cm)$^{-1/2}$". Calculate $\sqrt{y}$ for each value of y and fill the column.
- Take a graph sheet and plot column 4 along the x-axis and column 3 along the y-axis.
- You will have to choose an appropriate scale.

3.2. Looking at the graph you have drawn, what can you say about the validity of the hypothesis?

3.3.

(a) From the graph, calculate the value of acceleration due to gravity and write down its value:

g = ________ cm s^{-2}

(b) How does your value compare with the expected value of g? Calculate the value of the percent fractional error

$$\frac{\Delta g}{g_{expected}} = \left| \frac{g_{experimental} - g_{expected}}{g_{expected}} \right| \times 100 \quad =$$

4. Reliability of data

4.1. Comment on any special difficulties you faced while performing this experiment.

4.2. State any precautions you took while performing the experiment.

4.3. According to you, what is the accuracy of your observations?

Data Assessment

1. Look at the data you have collected and fill the following table. This table will provide at a glance a summary of the important aspects of your data.

   Note:
   - Some aspects require numeric data.
   - For qualitative aspects, write Yes/ No or whatever your answer maybe.

	Aspect of Data	**Value / Response**
A.	Height from which coin is dropped	
	(i) Minimum value of height y_{max}	
	(ii) Maximum value of height y_{min}	
	(iii) Range (y_{max} - y_{min})	
	(iv) Choice of interval *dy*	
	(v) If heights chosen are equidistant (Yes / No)	
	(vi) Total number of heights investigated	
B.	Number of repeats taken for time of fall (*n*)	
C.	Graphical display of data as ($\sqrt{y}$, t) graph	
	(i) Choice of scale along X-axis	
	• Quantity plotted along X-axis	
	• Value of X_{min}	
	• Value of X_{max}	
	• Least count of X-axis	
	• Units	
	(ii) Choice of scale along Y-axis	
	• Quantity plotted along Y-axis	
	• Value of Y_{min}	
	• Value of Y_{max}	
	• Least count of Y-axis	
	• Units	

	Aspect of Data	Value / Response
D.	Nature of Curve fitted through data points ($\sqrt{y}$, t)	
	(i) Functional Form	
	• Straight Line	
	• Parabola	
	• Any other	
	(ii) Method used for drawing the curve	
	• Best visual fit	
	• Method of least squares	
	• Any other	
	(iii)Scatter of data points about the curve drawn	
	• Hardly any scatter	
	• Reasonably small scatter	
	• Large scatter	
	(iv) Intercept along X-axis	
	• Zero	
	• Nonzero (state value)	
	• Can't say	
	(v) Intercept along Y-axis	
	• Zero	
	• Nonzero (state value)	
	• Can't say	
E.	Slope of the curve	
	(i) Method of calculation	
	• Calculation from one point	
	• Calculated as dY/ dX	
	• Any other method	
	• Not calculated	
	(ii) Value of slope	

	Aspect of Data	Value / Response
F.	Value of g	
	(i) Method of calculation	
	• Calculation for each data point	
	• Calculated from slope of straight line as dY/dX	
	• Any other method	
	• Not calculated	
	(ii) Reported value of g	
	• Units	
	(iii) Expected value of g	
G.	% error	
	(i) Value of absolute error $\left\|g_{calculated} - g_{exoected}\right\|$	
	(ii) Value of % relative error	
H.	Validity of hypothesis	
	• Data supports hypothesis (Yes / No)	

2. The following table will help you assess if your measurements match the theoretically expected values for the time of fall. Use your data to complete the table below:

S. No.	Measured height y (m)	Measured Time t (s)	Theoretically Expected value $T_{theo} = \sqrt{2y/g}$ (s)	Difference $\left\|t - t_{theo}\right\|$ (s)	% Relative Error $\left\|\frac{t - t_{theo}}{t_{theo}}\right\| * 100$

2.1 On the basis of the above table, state how confident are you about the

(a) value of g that you have reported

(b) claim about validity of the hypothesis

Bridging Exercises

I. Reaction Time

1. Meena was set the task of measuring the time taken by her classmates to run 50 m. She made each one run by turn and diligently recorded the time taken as carefully as she could. She declared Reena with a timing of 13.2 s as the fastest runner in the class and Anju with a timing of 13.4 s as the second fastest. However, Anju challenged her decision saying, "You were too slow in stopping the stopwatch in my case!" Meena was indignant and immediately retorted: "Impossible. I don't cheat and stopped the stopwatch as soon as each of you crossed the finishing line." Reena said, "Yes, I am sure she did." However, Anju remained unconvinced and said, "I am not saying Meena did this deliberately. I am just saying that somehow she didn't time me right."

1.1. If you were asked to time the runners,
  (a) would have done a better job than Meena? (Yes/ No)

  (b) Justify your answer.

1.2. You and your partner are making a time measurement for a race. Place a tick mark to indicate which of the following procedures is a better way of measuring time:
  (a) You call "Start!" just as the race starts and "Stop!" when the runner crosses the finish line while your partner holds the stopwatch and actually carries out these instructions.
  (b) The same person (you or your partner) undertakes both the tasks, that is, deciding when to start/stop the stopwatch and pressing the buttons.

1.3. Explain why one procedure is better that the other.

2. The class had a debate on the procedure to use for reporting the time taken to run a race.

   2.1. Place a tick mark to indicate which method you would adopt:
   - (a) Time each student just once and take the value as such.
   - (b) Time each student five times and take the average time.
   - (c) Time each student five times and take the least time.
   - (d) Time each student five times and take the value of time that repeats the maximum number of times.

   2.2. Anju had objections to the procedures (b), (c) and (d) given above. She said: "I get tired every time I run a race and if you make me do it three times, I will get slower each time. You better record the time accurately the first time I run just as they do in Olympics."

   According to you, what is the procedure adopted for recording the time taken to run a race in competition sports?

   2.3. If we presume that each time Anju runs the race, her performance remains the same, using an ordinary digital stopwatch,
   - (a) would you expect to get the same timing each time she runs? (Yes/ No)
   - (b) Explain your answer.

3. In an experiment to determine the time it takes for a coin to fall from a fixed height, Sara repeated the experiment five times under *identical conditions*.

   3.1. Explain what she means by the term *identical conditions*?

   3.2. Would you expect to get the same time of fall each time she drops the coin? (Yes/ No)

3.3. Justify your answer.

3.4. Place a tick mark to indicate which method she should adopt to report the time of fall:
(a) Report the average all five measurements of time.
(b) Report the value of time that repeats itself the maximum number of times.
(c) Report the maximum value of time.
(d) Report the value of time that repeats itself in consecutive measurements.

4. You have to stop the digital stopwatch (least count 0.01 s) exactly after 10.00 s.

4.1. If you were to repeat this ten times, make a prediction and record what values of time the stopwatch is likely to actually show in the table given below.

Trial	1	2	3	4	5	6	7	8	9	10
Time (s)										

4.2. Now take the digital stopwatch and actually try to stop the stopwatch after T=10.00 s, then 1.00 s and 0.50 s. Record your data for 25 repeats in table below:

Time read when stopwatch is stopped at T = 10.00 s			Time read when stopwatch is stopped at T = 1.00 s			Time read when stopwatch is stopped at T = 0.50 s		

4.3. In the table given below, fill the columns to indicate what you would report as the time it actually takes you to stop the watch when you attempt to stop it at a particular value of time and the corresponding errors.

Specified Time T (s)	Time taken to stop the stopwatch T_{actual} (s)	Absolute error $(T - T_{actual})$ (s)	% error = $\left\| \frac{(T - T_{actual}) * 100}{T_{actual}} \right\|$
10.00			
1.00			
0.50			

4.4. On the basis of this data, indicate which of the following statements is true:

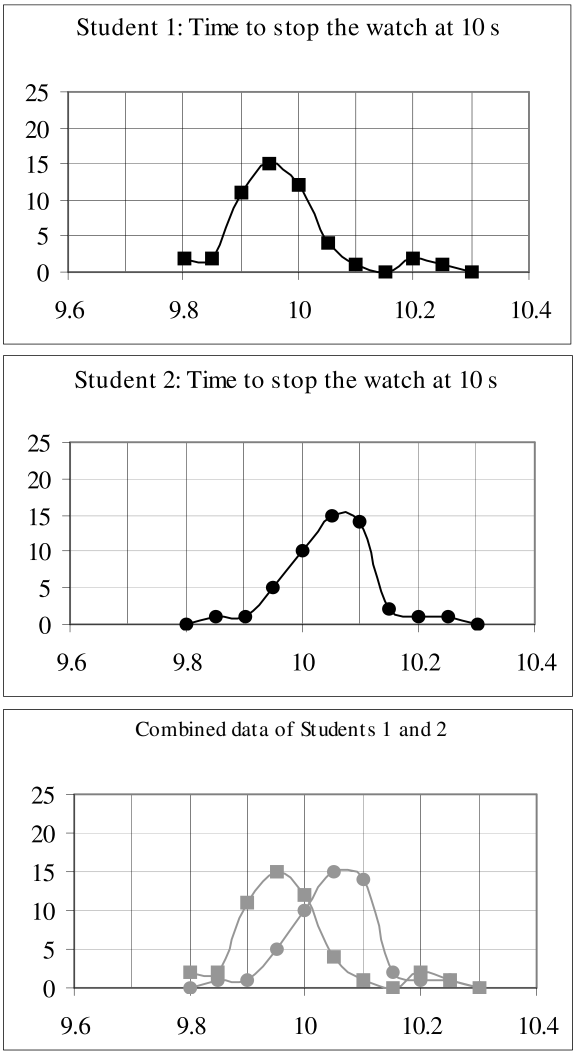
(a) Larger the time interval being measured, larger the relative error due to reaction time.
(b) Smaller the time interval being measured, larger the relative error due to reaction time.
(c) Larger the time interval being measured, larger is the reaction time.
(d) Smaller the time interval being measured, larger is the reaction time.
(e) Reaction time of a person is always the same and is a constant.

5. Fifty repeat measurements taken by two students when they attempted to stop the stopwatch at T=10.00 are plotted in Figures a and b (next page).

5.1. When their data is combined together, draw the distribution curve for the 100 data points in the space provided in Figure c.

5.2. Use the data plotted in Figure to complete the table given blow.

Observer Summary of Data	S1	S2	S1 and S2
Minimum value of T_{actual}			
Maximum Value of T_{actual}			
Average Time			
Standard Deviation			
Absolute error $(T - T_{actual})$			
% Relative Error = $\left\| \frac{(T - T_{actual}) * 100}{T_{actual}} \right\|$			



5.3. Explain if there any advantage in combining the data of the two observers.

II. Anomalous Data

1. Rohan took ten repeats measurements of the time it takes for a one rupee coin to fall from a height of 1.5 m. He took all possible precautions and claimed that he had repeated the experiment under identical conditions. His data is tabulated below.

No.	1	2	3	4	5	6	7	8	9	10
Time (s)	0.58	0.66	0.55	0.54	0.53	0.52	0.57	0.56	0.54	0.53

1.1. Do you trust his observations? Explain why.

1.2. What could be the possible reasons for the variations in the measured values of time?

1.3. What should Rohan report as the result? State how you arrived at this value.

2. Ahmed took five repeat measurements of the time it takes for a one rupee coin to fall from a height of 1.5 m. His data is tabulated below.

No.	1	2	3	4	5
Time (s)	0.55	0.52	0.62	0.53	0.55

2.1. What should Ahmed report as the result? State how you arrived at this value.

2.2. Ahmed decided to take five more measurements. All the ten observations are tabulated below.

No.	1	2	3	4	5	6	7	8	9	10
Time (s)	0.55	0.52	0.62	0.53	0.55	0.53	0.62	0.54	0.51	0.58

2.3. What should Ahmed report now as the result? State how you arrived at this value.

2.4. Have you used the same procedure for calculating the result in the two cases? Justify your answer.

3. Meena's data for the time of fall from a height of 1.5 m is as below.

No.	1	2	3	4	5	6	7	8	9	10
Time (s)	0.83	0.79	0.78	0.81	0.84	0.80	0.84	0.82	0.78	0.85

3.1. What should Meena report as the result? State how you arrived at this value.

4. All three students performed the experiment using the same procedure and identical setups.

   4.1. What could be the reason for the students reporting different values of the time of fall from the same height?

   4.2. Is it okay for all three students to combine their data and report a single value of time of fall? (Yes/ No)

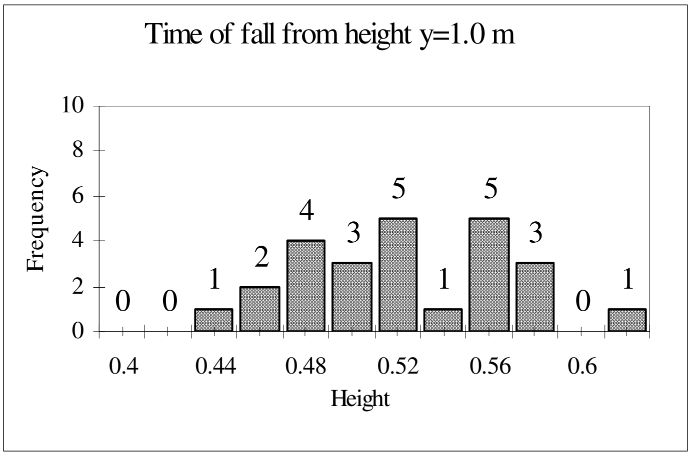
   4.3. If yes,
   (a) what should they report as the result?

   (b) How did you arrive at this value?

   4.4. If no, explain why.

5. Simon took 25 repeats for the time of fall from three different heights. He plotted the histograms depicted in Figure on the next page.

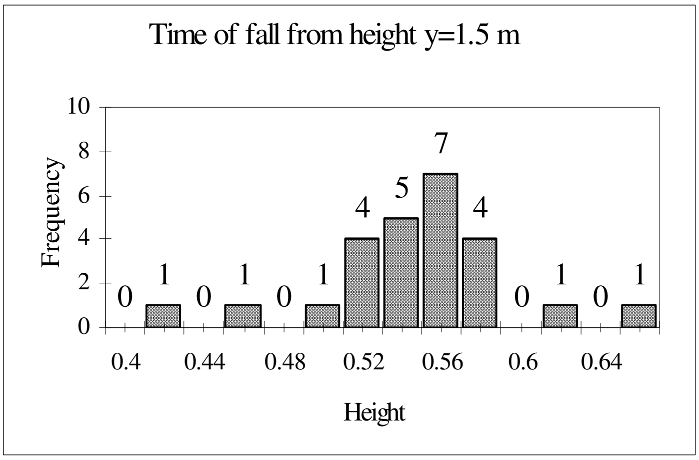
   5.1. In each case, in the space provided alongside the figure,
   (a) indicate the values of time, if any, that he should reject from the data set.
   (b) what should he report as the result.
   (c) explain how you arrived at your answer.



(a)
Data points (if any) to be rejected from the set:

Reason:

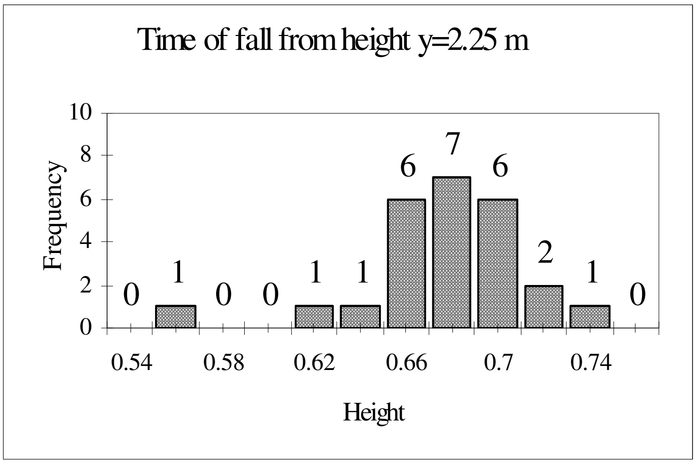
Value of fall time:



(b)
Data points (if any) to be rejected from the set:

Reason:

Value of fall time:



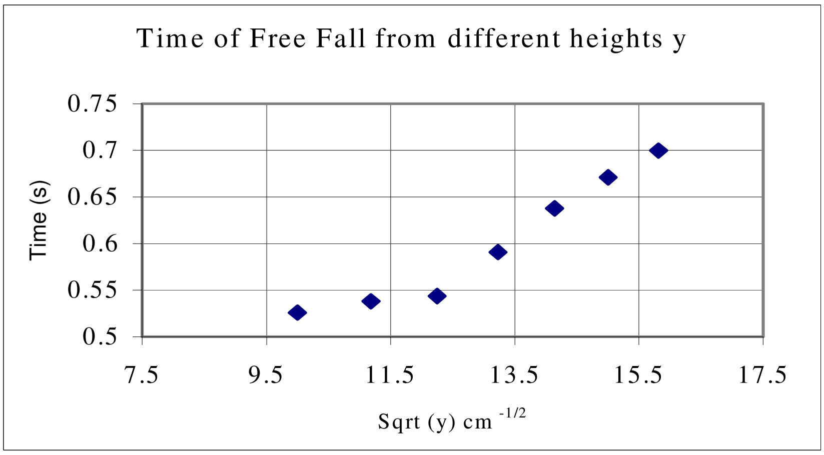
(c)
Data points (if any) to be rejected from the set:

Reason:

Value of fall time:

III. Graphical Analysis

1. Rohan's results for the time of free fall for different heights are plotted below.



1.1. Draw the curve that Rohan should draw through these data points.

1.2. Does this data support the hypothesis $t = \sqrt{\frac{2y}{g}}$?

(a) Yes/ No.

(b) If yes, what is the range of heights over which the hypothesis is valid?

(c) Justify your answer.

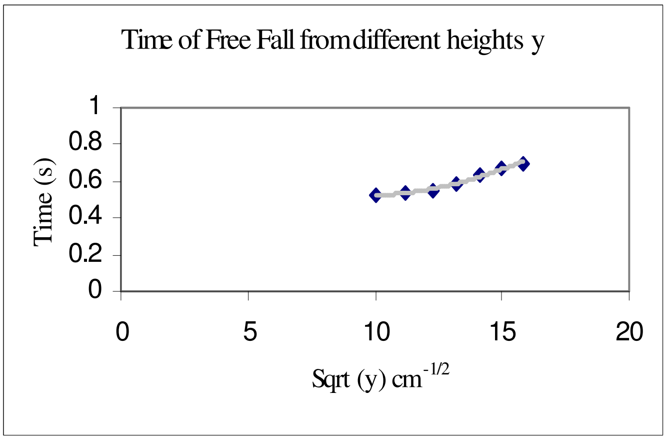
1.3. Do you expect the error in measurement of time to be the same for each data point?

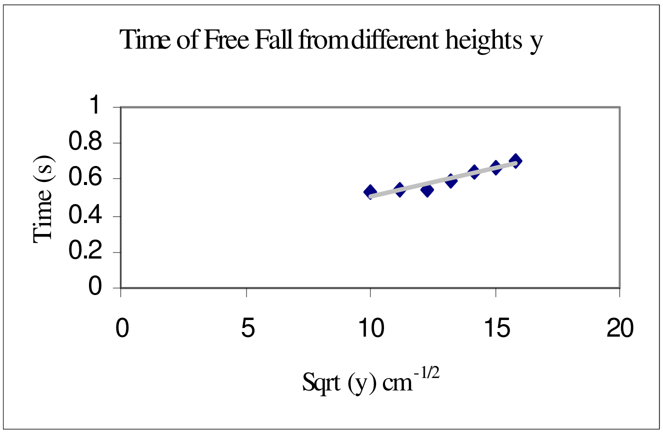
(a) Yes/ No.

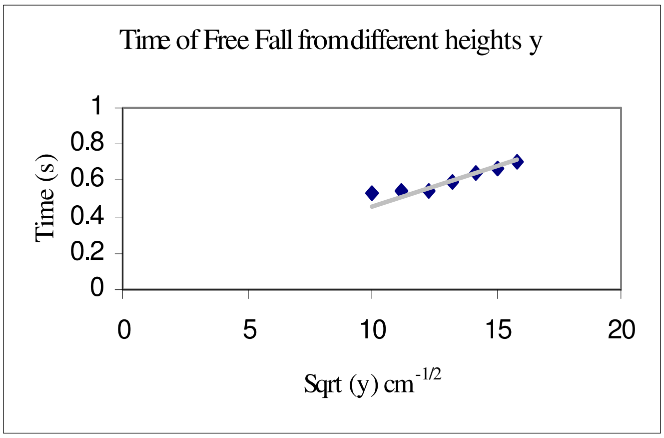
(b) Justify your answer.

2. Seema plotted the same data on a different scale as shown in Figure below.

2.1. According to you, which of the three curves (a), (b) or (c) best represent the data?







2.2. Justify your answer.

2.3. Does the curve you have chosen through the data support the hypothesis $t = \sqrt{\frac{2y}{g}}$?

(a) Yes/ No.

(b) If yes, what is the range of heights over which the hypothesis is valid?

(c) Justify your answer.

2.4. Would Seema be justified in rejecting the first two data points?

(a) Yes/ No.

(b) Justify your answer.

IV. Errors in measurement

1. Rohan's data for y=1.5 m and how he computed g and percent relative error in value of *g* is shown below:

y = 1.5 m
Number of repeat measurements $N = 5$
$t_i(s): (0.55, 0.52, 0.62, 0.53, 0.55)$

$$t_{average} = \frac{1}{N}\sum_{i=1}^{N} t_i = 0.554 \text{ s}$$

$$g_{expt} = \frac{2y}{t_{av}^2} = 9.77466 \text{ ms}^{-2}$$

Value of *g* expected at New Delhi:
Lattitude of New Delhi φ=28.34 N
Altitude of New Delhi $h = 210\ m$

$$g_{expected}^{NewDelhi} = 9.780490(1 + 0.0052884\sin^2\phi - 0.0000059\sin^2 2\phi) - 3.086x10^{-6}h \qquad ms^{-2}$$
$$= 9.780064\, ms^{-2}$$

$$\%\text{ Relative Error} = \left|\frac{g_{expt} - g_{expected}^{NewDelhi}}{g_{expected}^{NewDelhi}}\right| * 100 = \left|\frac{9.77466 - 9.780064}{9.780064}\right| * 100 = 0.055\,\%$$

1.1. According to you, can Rohan claim that he got the result correct to 0.055%?

2. According to you,

2.1. What is the uncertainty in the value of time $t_{average}$ in Rohan's data? Show how you estimated this value.

2.2. What is the uncertainty in the value of g calculated from Rohan's data? Show how you estimated this value.

2.3. What is the number of significant figures to which Rohan should report his result?

Laboratory Activity II

You are given two coins of different radii and mass. You are required to

- Determine the relation between the height y and the time of fall.
- Determine the value of acceleration due to gravity accurate to 2%.
- Establish if the hypothesis that the time of fall is independent of the mass of the falling object is valid.
- Establish if the hypothesis that the acceleration due to gravity is independent of the mass of the falling object is valid.

Note:

In this session, you will work in a group of four students and report a common result. A suggested strategy for group work I that you

- First take independent observations;
- Resolve discrepancies between individual student data;
- Then combine the data taken by all four students in the team; and finally
- Proceed to analyze the data and report a common result.

You would have to take a decision about how to proceed and how to present your data and results.

International Conference on Physics Teacher Education Beyond 2000, Select Contributions. R. Pinto and S. Surinach (Editors), 319-324, Elsevier (Ansterdam)

DEVELOPING A RESEARCH-BASED LABORATORY CURRICULUM FOR COLLEGE PHYSICS

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ABSTRACT

We recently launched a pilot study to systematically identify elements of procedural and conceptual knowledge that play a critical role in science experiments. The research instruments consist of specially designed laboratory activity sheets imbedding careful sequence of concept-questions, instructional-cues and experimental-tasks. The rubric used for evaluating students' performance and quality of data collected in a simple laboratory task is presented. Data shows deficient knowledge of procedural concepts; students do not use their understanding of physics to decide the values and range of measurement variables or check the validity of results. However, the overall validity of a hypothesis is judged using theoretical expectations rather than the data collected. Based on these findings, a three-step model of laboratory learning is proposed. At level one, students answer a pre-laboratory questionnaire on design of the experiment and procedures to be adopted. Then they perform the laboratory task taking crucial decisions about data collection. Level two aims to facilitate transition from novice to expert behavior. Here students assess their data and undertake simple bridging exercises designed to enhance procedural understanding and experimental skill. Level three tests the expertise gained. As an example, a laboratory tutorial based on this model is described for a specific task.

1. INTRODUCTION

In recent years, a great deal of effort has been directed towards gauging efficacy of teaching practices and identifying common misconceptions and learning difficulties that prevail in the various domain areas of physics theory. However, surprisingly little research has been carried out, particularly at the tertiary level, to identify understandings that underpin laboratory performance [1, 2]. Inasmuch as experiments, demonstrations and hands-on activities play a pivotal role in the learning of physics, there is an urgent need to extend the methods of physics education research to learning in the laboratory. We have recently launched a pilot study to systematically explore undergraduate physics students' understanding of

1. aim of the laboratory task and design of experiment;
2. variables of measurement and their character;
3. concepts of reliability and validity of data; and
4. how empirical evidence is used to test hypothesis;

The formulation of the problem as above has been influenced by the seminal work done by earlier researchers who have explored these aspects in younger children [3-6].

Laboratory tasks involve many parameters and it is usually not possible to study the affect of any of these in isolation. Suitable control experiments, leave aside complete learning environments, are difficult to design. To make a beginning, we tested two universal conjectures. First, when students are given a well-defined experimental task with complete instructions on how to acquire, handle and interpret data, they are usually able to execute the algorithm satisfactorily. On the same well-defined task, performance deteriorates when critical decisions such as what the range of variables should be and how many observations should be taken, are left to the student. Further, if the same task is worded differently or embedded in an unfamiliar context, the difficulty level increases manifold. Competence and transfer of learning are not assured. Second, when students are given an open-ended investigation without first executing a well-defined sample task, their performance is extremely deficient. Left to their own resources, students often face additional difficulties in evoking appropriate concepts to design the setup, identifying variables of the problem, establishing procedures for measurement and making sense of the data they gather.

These tenets, verified through several classroom investigations [7], have helped us in designing research instruments which incorporate an optimum sequence of instructions, cues and sample tasks alongside the research questions that seek data on select aspects of conceptual and procedural knowledge. The results of these investigations are being used to design a comprehensive research-based laboratory curriculum for use at the tertiary level. In this paper, we describe one of the research instruments and suggest a rubric for evaluating the quality of students' data. Finally, we propose a model of laboratory instruction and exemplify it through an Interactive Laboratory Tutorial that could be used to enhance students' concepts of procedure.

2. RESEARCH METHODOLOGY

2.1 Design of Research Instrument

A deliberate attempt has been made to probe students' understandings operative in contexts with which the students are familiar and which qualify in their perspective as scientific investigations. The research instrument described herein pertains to a block of activities titled "Test a Hypothesis." The unit contains five different activities. In each case, the problem required the student to determine the relation between two physical quantities. Specifically, they investigated the

a. time it takes a coin to fall from different heights;

b. horizontal distance traversed by a ball launched from different heights with a fixed velocity;
c. change in the resistance of a light detecting resistor with intensity of light;
d. change in current in a torch bulb as the voltage is varied;
e. change in level of water flowing out of a burette with time.

For each activity, the students were required to work through

I. A Pre-laboratory Questionnaire. This was a paper-and-pencil instrument that probed students' ideas about

- design of experiment; what apparatus would be required and how it would be used.
- procedure for data collection; what physical quantities would be measured, how many sets of observations would be taken and how the raw data would be tabulated.
- procedure for analysis; how the data would be analyzed, for graphical analysis what would be plotted on the X- and Y-axes and what would be the sketch of the curve.
- physics of the problem; this entailed posing few conceptual questions about the underlying principles and seeking the mathematical relation between the measured quantities.

II. A Laboratory Activity Sheet. This embedded the laboratory task within a carefully worked out sequence of exposition and questions. Instructions delineated details about

- design of experiment; how the setup was to be used.
- procedure for data collection; how observations were to be taken and tabulated in data sheets with labeled columns provided for the purpose.
- hypothesis to check; this entailed describing briefly the physics of the problem and the essential steps in deriving the mathematical relationship between the two physical variables.
- procedure for graphical analysis; what related quantities to calculate, how to tabulate derived quantities in columns provided in the given data sheets, and what to plot on the X- and the Y-axes.

Parameters crucial for successful completion of the task, however, were not spelt out. What the students had to do included

- deciding the values and range of measured quantities;
- deciding the number of repeats of measurement;
- calculating derived quantities from raw data;
- choosing an appropriate scale and plotting data points;
- drawing an appropriate curve through the data points;
- interpreting the result by looking at the graph drawn;
- inferring the validity of the given hypothesis;
- calculating a physical parameter of interest from the data or the slope of the graph; and
- specifying their level of confidence in the data and errors of measurement

These subtasks define the students' skill as an experimenter and adjudge how well the whole task is ultimately executed.

2.2 Data Collection

The Laboratory Questionnaire and the Activity Sheets were administered to students in the II year of the B.Sc. Physics Honors course in one of the prestigious colleges of Delhi University. The small population of 14 students facilitated in-depth analysis of data. Bits and pieces had however, been tested earlier with sample sizes extending from 100 to 300 students. The study was carried out at the end of the formal academic session just after a traditional laboratory examination. Thus it is safe to presume that the students were highly focussed and prepared for the task.

2.3 Criteria for Analysis

Student's answers to the concept probes were analyzed empirically. An attempt was also made to identify aspects of formal laboratory instruction that could have influenced a particular answer. For the laboratory task, the students' data was minutely scrutinized and evaluated in accordance to a specially constructed criteria list that looked at the students'

- choice of minimum and maximum value of the physical quantity taken as the independent variable x;
- choice of interval dx between consecutive values of x;
- number of sets of observations and number of repeats;
- scatter in repeated values of the physical quantity taken as the dependent variable y;
- overlap between the set of repeats for the variable y corresponding to consecutive values of the variable x;
- choice of scale for plotting the graph between x and y;
- correctness of the plotted points;
- graphical scatter of the plotted data points about a hypothetical curve;
- correctness of the curve fitted through the data points;
- method of determining the slope and its value;
- calculation of a physical quantity or parameter from the value of the slope;
- reporting of the result; and
- reporting of the errors of measurement.

Further, the entire class data was one, compared to check the consistency in the group performance and two, compared against the data we had taken ourselves on identical setups.

3. ANALYSIS AND DISCUSSION

We report herein the results of only one activity in the unit. In this, the students were given a one rupee coin and asked to determine the relation between the height (y) and the time of free fall (t) and find the value of acceleration due to gravity (g). Of the five tasks, this activity posed the least cognitive challenge. Hence it is appropriate for bringing forth how in a well understood task, the reliability and validity of students' data affect graphical analysis and the ability to test the validity of a hypothesis.

3.1 Conceptions About Design Of Experiment

The pre-laboratory questionnaire asked the students to describe the complete procedure for making the necessary measurements. All the students stated they would drop the coin from different heights, record the time using a stopwatch and tabulate these two quantities. All except one student also said they would plot a graph to determine the relationship between y and t. However, there were surprising variations in students' thinking about important details.

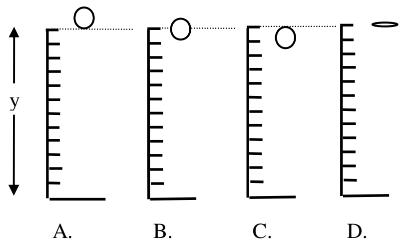

Figure 1: Students were asked the most appropriate way of placing the coin before it is dropped from a height *y*.

Height from which coin should be dropped. Asked to suggest the values of height, half the students chose the range of *y* as 20 to 120 cm. Five students suggested values varying from 1 to 3 m while one student wanted to drop the coin from 10 m. Only one student stated that she would choose the heights after some trial. The students who planned to drop the coin from 20 cm had not considered how accurately the time of fall could be measured using an ordinary digital stopwatch. Likewise, the student who planned to drop the coin from ten meters had not thought of how from that height she would ascertain the exact moment when the coin would hit the ground. She also did not ponder over how air friction and air currents would affect the fall.

Method of placing the coin. We asked the students to choose which of the four different ways of placing the coin at its rest mark shown in Figure 1 was the most appropriate. Ten students opted for placing the coin face down as shown in (d) while three students chose the edge down configuration (a). One student chose to align the middle of the coin with the marker as in (b). These answers reflect that while the majority of students understand how the height should be measured to avoid an offset error, they are oblivious of the fact that a coin dropped face down is likely to wobble more than a coin dropped edge down. Asked explicitly if the way the coin is dropped would change the time of fall, the student's opinion was divided almost equally (Table 1).

Theoretical Relation between height and time of fall. Study of freely falling objects is one of the first episodes covered in any course in Newtonian mechanics. However, when asked to give the time it would take for a coin to fall from a height of 1 m, only nine students gave the correct answer of $t = \sqrt{2/g}$. The remaining students quoted a variety of unacceptable formulae. When we checked if the student's believed the time of fall depended on the mass of the coin, the common belief that heavier objects fall faster was much in evidence (Table 2). No explanation of this thinking was forthcoming.

Table 1: Students' prediction about the time of fall for coin dropped edge down and face down being different.

Response Category	No. of Students
Yes: Coin dropped edge down is faster	4
Yes: Coin dropped edge down is slower	2
Yes: No further elaboration	2
No: No further elaboration	5
No response	1

Table 2: Student's response to which of the three given coins (Rupee 5, Rupee 1 and Paise fifty) would fall first. Coins are listed in the order of decreasing weight.

Response Category	No. of Students
All coins will take the same time	6
Rupee 5 coin will fall faster	6
Fifty paise coin will fall faster	2

Predicting the Graphical Relation. To check if the students understood how the data could be analyzed graphically to discover the relation between *y* and *t*, we first asked what they would plot along the X- and the Y-axes. The responses are summarized in Table 3.

Table 3: Students' choice of independent and dependent variables for graphical representation of data

Quantities Plotted along X- and Y-axes	No. of students
(X, Y): (y, t)	9
(X, Y): (t, y)	4
(X, Y): (t, y^2)	1

The response shows the inability of many students to correctly identify the independent and the dependent variable. This data belies the presumption that students have sufficient drill and practice in traditional laboratory to realize that the independent variable is generally plotted along the X-axis.

Next we asked students to sketch what they expected the graph describing the relationship to look like. A blank space with two unlabeled axes was provided for the purpose. Of the nine students who knew the correct formula, only four students could draw an acceptable graphical representation. All of them took time along the X-axis; three sketched the (t, y) curve as a parabola while one drew (t^2, y) as a straight line. The observation that the students are more comfortable taking time along the X-axis has been found in other contexts as well. The sketches of the remaining students merely confirmed another well established research finding that students have a major problem in translating a formula into a graph.

3. 2 Quality of Laboratory Performance

After completing pre-laboratory questionnaire, the students proceeded to actually carry out the experiment. To ensure that the exercise was carried out under fairly controlled conditions, the Activity Sheet clearly spelt out the procedure step by step and showed students how the coin was to be placed. A measuring tape was stuck on the wall to facilitate measurement of height. The bottom of the tape was at 1 m from the ground to cue a reasonable starting value. The students were expected to take note of this offset in recording the height. Table 4 summarizes the quality of student's data along the dimensions listed in the checklist given in section 2.

Table 4: Making sense of student's observations/ results.

Aspect of Data and Response Category	#
A. Recording height from which coin is dropped	
Apparently correct	11
Apparently Incorrect	3
B. Recording time of free fall	
Apparently correct	5
Wide variations in fall time	7
Apparently incorrect	2
C. Choice of range of *y*	
From 120 cm to 300 cm	9
From 70 cm to 150 cm	2
From 20 cm to 50 cm	3
D. Number of heights chosen	
4 to 5	10
6 to 10	4
E. Choice of interval *dy*	
5 to 10 cm	6
20 to 25 cm	7
50 cm	1
F. Number of repeats taken for time of fall	
10	1
2 to 3	4
One	9
G. Scatter in data about a hypothetical straight line	
Hardly any scatter	6
Reasonably small scatter	5
Unacceptably large scatter	3
H. Fitting a curve (X, Y): ($\sqrt{y}$,*t*)	
Fits straight line: apparently best visual fit	7
Fits a straight line: not the best visual fit	2
Fits a parabola: apparently best visual fit	4
Fits a complicated curve through all points	1
I. Value of intercept	
Nonzero	14
J. Calculation of slope	
Correct calculation from the straight line drawn	5
Incorrect calculation from the straight line drawn	3
Using mirror to calculate slope of the curve drawn	3
Not calculated	3
K. Reported value of '*g*'	
Less that 15 cm s^{-2}	3
Between 150 and 400 cm s^{-2}	4
Between 600 and 800 cm s^{-2}	2
Between 900 and 1030 cm s^{-2}	4
Not calculated	1
L. Reported value of % error	
Less than 5%	3
Between 10% and 30%	6
Greater than 50%	4
Not calculated	1
M. Concluding data supports hypothesis $t = \sqrt{2y/g}$	
Yes: Hypothesis is valid	12
No: Hypothesis is not valid	1
No response	1

<u>Measurement of height and time of fall.</u> While most of the students were able to measure the heights chosen correctly, the time data of more than half the class showed wide variations and unexpected values. In the pre-activity question, students had said they would repeat the measurement of time at each height; eleven suggested up to 5 repeats while three suggested taking 15 to 25 repeats. Of these, one student had this to say: " … four times with each side (heads/tails) facing N, S, E, W in turns so as to eliminate errors due to air current variations." This is an interesting comment that reflects the vividness with which surface features of a problem motivate students to visualize how they will execute a task. However, despite intentions, in actual practice, more than half the class took only one measurement of time for each height.

<u>Inferring the validity of the hypothesis.</u> The students were asked to compute $\sqrt{y}$ and plot *t* with respect to $\sqrt{y}$. The quality of measured data was gauged by looking at these ($\sqrt{y}$,*t*) plots. The data of eleven students showed reasonably small scatter about a hypothetical straight line. However, only nine students drew a straight line while 4 students drew a parabolic curve. One student drew a complicated curve passing through all her data points. None of these curves could be extrapolated to pass through the origin.

The activity required the students to look at the nature of the ($\sqrt{y}$, *t*) curve and state if the observations supported the hypothesis $t = \sqrt{2y/g}$. Despite the fact that only nine students drew a straight line through the data points, as many as twelve students claimed the validity of the hypothesis. Then they proceeded to calculate the "slope" of the curve drawn and thence the value of *g*. Three of the students who had drawn nonlinear curves used a mirror to evaluate the slope at some arbitrary point on the curve and used this value to compute *g*! These students did not ponder on why they had obtained a nonlinear curve but allowed that picture to trigger memory of how slope of a nonlinear curve is obtained. The transfer of a procedure recommended to them in other contexts where nonlinear curves appear (such as the experiment to determine Stefan's Constant), allowed them to proceed further in their slated task despite its inappropriateness in the present situation.

<u>Reporting the value of g and percentage error.</u> Using the value of the slope – however computed – students reported values of *g* ranging from 4.58 cm s^{-2} to 1029.4 cm s^{-2} (the significant figures are as reported by students). However, the percent error from the accepted value of 980 cm s^{-2} were all less than 60%. These values, however, cannot be taken at the face value; in most cases the calculations hide gross errors. Of the four students who reported *g* between 900 and 1030 cm s^{-2}, one had obtained a nonlinear curve and found the slope at an arbitrary point; another had made a numerical error in calculating slope; two had erroneous values of height ranging from 0 to 40 cm and thus meaningless data from the outset. All the three students who obtained extremely low values of *g*, took quantities with mismatched units while computing the percent error. To exemplify, one student reported

Calculated value of *g* = 11.8 cm s^{-2}
Expected value of *g* = 9.8 m s^{-2}
% error = (9.8-11.8)*100/9.8 = 20.408%

It would appear that obtaining a value close to 9.8 made the students oblivious to the fact that only quantities with similar units can be compared; it is meaningless to compute percentage error when the observed value differs from the accepted value by two orders of magnitude.

Evaluating the "Goodness" of Raw Data. The above findings lead to the unfortunate conclusion that not one student had performed the experiment satisfactorily to the end. Discomforted by this thought, we undertook to evaluate the worth of the data collected by each student. First we compared the values of time with what we had ourselves measured. Then, we used the method of least squares to draw the best curve through the student's data points ($\sqrt{y}$,*t*). Finally, where applicable, we calculated the value of *g* the student would have reported had she used the correct procedure for evaluating it. Since none of the students had taken care to set the intercept at zero, we also checked how forcing the intercept to zero would affect the correlation in data and the value of *g*.

Observations taken by only three students survived the scrutiny. Table 5a summarizes the characteristics of their raw data. They are amongst the few that have an appropriate choice for the range of *y*, the interval *dy*. The higher than expected values of time are because of the very few repeats.

Table 5a: Select students' measured data. S identifies the data taken by students and R by the researchers.

ID	Range of *y* (cm)			Range of *t* (s)		Heights chosen	Rep-eats
	Min	Max	*dy*	Min	Max		
S1	150	250	50	0.55	0.78	5	3
S2	150	225	25	0.53	0.79	4	10
S3	150	250	25	0.59	0.84	5	3
R	150	250	25	0.54	0.71	5	25

Table 5b gives the parameters of the best fit and the value of *g* calculated therefrom. Second row in each cluster shows how the slope and value of *g* would change when the intercept is set to zero. In each case, forcing the ($\sqrt{y}$,*t*) straight line through the origin improves the value of *g* but also decreases the correlation. The data shows the extent to which bad graphical analysis can influence results. Only one student's observations yield a value of *g* with about 5% error. Ironically, left to her own devices, this student produced a value of ~ 5 cm s^{-2}.

Table 5b: Results of rigorous analysis of data carried out by researchers to evaluate quality of observations. R identifies data taken by the researchers.

ID	Using Linear Least Square Fit				Quoted value of *g* cm s^{-2}
	Slope	Inter-cept	Corr-elation	*g* cm s^{-2}	
S1	0.06 0.05	-0.20 0	0.98 0.95	550 929	4.9
S2	0.09 0.05	-0.53 0	0.96 0.87	253 791	945
S3	0.06 0.05	-0.16 0	0.95 0.94	498 737	385.8
R	0.045	0	0.99	1000	1000

3.3 Summary

On the face of it, the experimental task is simple and involves straightforward measurement of a static distance and timing of an event. However, successful performance hinges on recognizing that the time of fall is less than one second for heights under 5 m. At very small heights, the reaction time is comparable to the time of fall and in the first instance, one would not expect to get accurate values. On the other hand, larger the height, more are the effects due to air friction and air currents. The challenge then is to choose optimum values of *y* to reduce both, the errors of measurement and errors due to undesirable effects. Since one expects a large scatter in data, to get reliable and valid results, it is extremely important to take several repeat measurements of time for each height and be able to recognize and discard anomalous data before taking an average. Further, to avoid overlapping measurements of time, consecutive heights have to be spaced by an appropriately large interval. It is meaningful to undertake graphical analysis and draw an inference only when the data passes this benchmark.

Our study shows that students do not use their theoretical understanding of physics to choose the values and range of measurement variables or check the validity of results they obtain. Nevertheless, they have great faith in the intuitive procedures they adopt and the correctness of their measurements. However, when it comes to judging the overall validity of a hypothesis, they take recourse to their theoretical expectations rather than the evidence provided by their data.

4. MODEL FOR LABORATORY INSTRUCTION

One of the objectives of laboratory training is to help the student outgrow novice performance and develop what is accepted as experimental expertise. This is not so much a matter of giving more hands-on experience to hone skills in manipulating equipment as of creating a minds-on environment to promote conceptual learning about procedures [8]. As evidenced by data, such learning does not occur naturally in a traditional laboratory. Before appropriate procedural concepts can take root, it is important to

- elicit deficiencies in performance;
- explicitly confront students with quality of their data assessed using an objective set of criterions;
- provide experiences that explicate the causes responsible for poor quality of data; and finally
- suggest alternative mechanisms, procedural and conceptual, for enhancing performance.

Analogous steps have been found to be successful in engendering conceptual change in the learning of theoretical concepts; we believe these steps would also provide a paradigm for learning in the laboratory.

4.1 Laboratory Tutorial

We have used the above model of laboratory instruction to construct teaching units that pertain to various procedural concepts. The implementation is at three levels. At each level, the specially designed worksheets integrate concept probes with hands-on activities.

Level 1: Eliciting Novice Performance.

(i) *Pre-laboratory Questionnaire*: This includes questions to elicit students' understanding about design of experiment, concepts of procedure and the physics of the problem.

(ii) *Laboratory Activity*: The worksheet provides the theoretical background and a guided exposure to the laboratory task. Inasmuch as many critical decisions about data collection are left to the student, the activity provides an opportunity for spontaneous play with the measurement process. Learning by hit and trial is a crucial in situations that are little understood.

Level 2: Facilitating Transition.

(iii) *Data Assessment*: The instrument helps the student to subdivide the whole task into subtasks and assess each step using a pertinent set of criterions. By comparing her data with that of an imaginary experimenter, the student is sensitized to deficiencies in her performance.

(iv) *Bridging Exercises*: The worksheet consists of a careful sequence of concept and data probes. Simple hands-on exercises and thought experiments provide analogous learning for each subtask and help the student make informed choices about the measurement parameters.

Level 3: Generating Expertise.

(v) *Laboratory Activity*: With negligible guidance, the new worksheet seeks a fresh hands-on performance on either the same task, suitably enhanced and extended, or a related application. The assessment of this activity determines the gain in learning and the success of the instructional process. Depending on individual requirement, the student may be required to cycle through the earlier steps in this process at her own pace.

It is in order to add that assessing the quality of data requires a certain degree of statistical rigor. To go beyond qualitative understandings, it is essential to introduce students to computer-based tools for data analysis at an appropriate point in the instruction sequence. At the tertiary level, this could be mandatory. Obviously, this new dimension brings its own pedagogic challenge.

Example

For the coin activity, the level one instruction is provided by the questionnaire and the Laboratory Activity Sheet described in section 2 as the research instruments.

At level 2, students' data assessment sheets employ the rubric evoked in Table 4. The bridging tutorial consists of two clusters. The first motivates the concept of reaction time through a story line. The students are asked to attempt to stop a digital stopwatch when it reads 10 s and record the data for 50 trials; explain the reasons for the scatter in values; decide what to report as a result; and, repeat the process for time values of 1 s and 0.5 s. They are encouraged to examine the relative accuracy of the results in the three cases and plot the histogram to develop a visual comprehension of the nature of the spread in data and answer why taking repeats of a measurement is necessary. Data taken by different students is compared and then the entire class data is clubbed to see what happens to the distribution and the result. The challenge is to reduce the errors due to reaction time as far as possible; this drill is useful in helping students be more agile.

The second set of questions ask students to examine data sets such as

S1: (0.58, 0.65, 0.55, 0.54, 0.53, 0.65, 0.57, 0.56, 0.54, 0.53)

S2: (0.55, 0.52, 0.58, 0.58, 0.62, 0.53, 0.54, 0.54, 0.51, 0.53).

Students have to state what they would report as the result. Through similar questions, they learn how to handle anomalous data points; compare the quality of data taken by different observers; differentiate between gross errors, systematic errors and random errors; and explore the notions of precision and accuracy of data in the context of the given task. Exercises used for enhancing procedural concepts invoked in graphical representation of data are not discussed herein but are adapted from the unit on graphing.

At level 3, students are asked to work in groups of four and challenged to determine g accurate to within, say, 2% and state the conditions necessary for reducing error. A natural extension to the group activity is clubbing the data of the entire class and discovering how this changes the distribution and the average value of the fall time for each height [9]. This sequence of instructional steps provides useful learning about the inherent limitation of the measurement process and methods for reducing the errors of measurement.

5. EVALUATION

While the various concept and data probes have been tested individually, we are in the process of testing the complete block in a classroom situation. Meanwhile, it would perhaps suffice to say that the student response to this form of instruction has been extremely enthusiastic. According to students, it is hands-on and minds-on.

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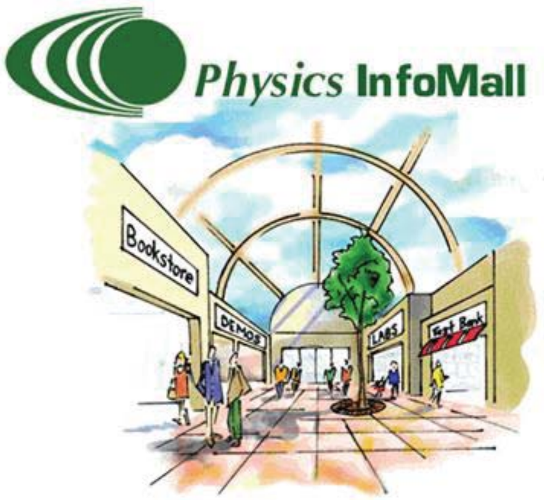

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The *Physics InfoMall* is a CD-ROM containing a large collection of physics resources for use by students and teachers. The information on the *InfoMall* is the equivalent of 35,000 pages of materials ranging from basic physical constants, to special interest topics, to templates for developing complete lessons.

This database is an information mall in the sense that a shopping center is a mall of consumer products. The *InfoMall* contains a variety of items from which to choose. It has textbooks, lab experiments, demonstrations, booklets, journal articles and many other documents. When a user enters the *InfoMall*, he or she may browse just as at a shopping mall. The teacher can enter the textbooks store by clicking on *Textbook Trove*, the problems store by clicking on *Problems Place* and so forth. When teachers have entered a store, they can look around and see what is available.

The Physics InfoMall contains a variety of materials that can help you with teaching. The major items are the goods in a store, namely the textbooks, lab manuals, etc. In addition, the entrance to the *InfoMall* has several options that can help with your teaching. From the *InfoMall Entrance* one can enter the "stores" in several different ways and have access to a calendar of events in the history of physics, tables of contents of major high school physics textbooks, a glossary of physics terms, an equations dictionary, and objectives for physics lessons. Any of these items can be used independently of the InfoMall database.

The *Physics InfoMall* contains:

- More than 1,000 demonstration and laboratory exercises in the Demo and Lab shop,
- More than 3,000 problems and solutions in the Problems Place,
- More than 3,000 articles from journals and magazines in the Articles and Abstracts Attic,
- Books that cover a wide range of topics from crystal growing to women in science in the Book Basement,
- The full text of 19 different highly regarded introductory level physics textbooks in the Textbook Trove,
- More than 100 equations linked to problems and graphics in the Equations Dictionary, and
- A historical Physics calendar

Contents of the Physics InfoMall

The Physics InfoMall was created about 15 years ago. Thus the formatting is not as nice as on today's databases. However, it contains much useful information.

ARTICLES & ABSTRACTS Attic

Over 3,500 articles selected from:

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Putting Physics Infomall on the hard drive of a PC.

When we created Physics InfoMall in the dark ages of the 20^{th} Century, 600 MB of data was considered extremely large. Thus, we set up the installation program so that only the executable programs and a few others were transferred to the hard drive. The data remained on the CD. Today, it is a pain to need to find the CD every time you want to use the library. Fortunately, it is relatively easy to get everything on the computer drive. The steps are given below.

On your computer drive create a folder called Infomall (e.g. C:\Infomall) Do not put the folder inside any folder which has a blank in its name (e.g. Program Files).

Copy the following folders from the CD to that folder:
COMMON
DOSMALL
STORES

Then copy two files to the same folder on the hard drive
SETUP.EXE
SETUP.INS

Now, remove the CD from the computer and go to the Infomall folder on the computer drive. Double click on SETUP.EXE

Answer “yes” to the questions that pop up and ignore the statement that you need the CD in the drive.

A Pedagogical Structure for Active Learning: The Learning Cycle

Introduction

The results of physics education research can influence our choice of subject matter, text, homework, and examinations. As instructors we would also like to influence our students' development of problem solving and reasoning skills. Research related to physics education and to cognitive science indicates that when individuals are learning a new topic or a previously studied topic in a new context, they need concrete-empirical experiences to help make the learning and understanding meaningful. Gradually they develop greater facility in physics and they are able to reason and problem solve without relying upon experiments or concrete experiences. In other words, "hands-on", "minds-on" experiences are essential prerequisites for the development of advanced abilities.

Classroom activities play a central role in the improvement of student abilities. Research on the cognitive development of college students in response to instructional experiences indicates that the structure of classroom activities may play a central role in both their understanding of the subject and the development of reasoning and problem solving skills.

Objectives

- To enable you to understand the "learning cycle" approach to physics teaching.
- To assist you in designing classroom activities that encourage active, meaningful learning.

Procedure

1. Participate in an investigation of simple measurement of force.

2. Discuss the Learning Cycle.

3. Participate in another activity.

Exploration

We will begin this module with a laboratory investigation. You have been provided with some rather common materials. With these materials devise two or more ways in which you can measure force in some arbitrary units. Your methods need to be able to be calibrated and should allow for measurements that will give the same answers (within reasonable measurement error) when repeated.

Record your observations and data below.

Describe the measuring schemes, their value and their limitations.

Essay - The Learning Cycle in Physics

Suppose you are planning to begin your course's section on conservation of momentum. How would you begin? Jot down what you would consider a useful way for your students to study this topic.

Now consider the proposed "beginnings" that follow. Rank from most useful (1) to least useful (7) for your purposes.

_____ (a) State Newton’s Third Law from which the results of conservation of momentum can be derived.

_____ (b) Arrange for a laboratory period in which your students can watch interactions of two objects such as small low friction carts of different masses and speeds. Ask the students to collect observations about any relationships that they observe.

_____ (c) Remind your students of their everyday experiences with momentum and invite them to describe some conclusions that are revealed by their observations.

_____ (d) Define momentum, state conservation of momentum as a general principle and then give some examples.

_____ (e) Ask students to predict the results of interactions between low friction carts. Then demonstrate the results.

_____ (f) Define momentum then provide a laboratory where your students are assigned to measure accurately the momenta of some objects before and after interactions.

_____ (g) Define momentum, state momentum conservation, then provide a laboratory where your students are assigned to verify conservation of momenta.

Discuss your rankings with others at your table. Record your thoughts below.

Your choice of method to introduce conservation of momentum will depend on your students' background, their previous experiences, your teaching environment, and your available resources. If all other things are equal and we base our choices on contemporary research in physics teaching and learning, we prefer the approaches in (b), (c), and (e). Each of these approaches are examples of the *exploration* phase in the learning cycle for planning of teaching activities. The entire learning cycle consists of three phases that are named *exploration*, *concept introduction*, and *application*. During *exploration* the students learn through their own more or less spontaneous reactions to a new situation. In this phase, they explore new materials or ideas with minimal guidance or expectation of specific achievements. Their previous knowledge and patterns of reasoning may be inadequate to cope with the new data, and they may begin obtaining a new view or seeing new patterns in interactions. The workshop exercise opening this module gave you an *exploration* experience.

During the *concept introduction* phase, a new concept is defined, a new principle introduced or an application is explained to expand the students' knowledge, skills, or reasoning. This step should always follow *exploration* and relate to the *exploration* activities. It will thereby assist in your students' modifying their conceptual view and learning. In the example of conservation of momentum above, for instance, alternative (a) represents a possible *concept introduction* phase, perhaps introduced via (c) as an intermediate step to relate *exploration* and *concept introduction*. An appropriate approach to the concept introduction is to build on the exploration and encourage individual students to "invent" part or all of a new idea for themselves, before you present it to the class.

During the last phase of the learning cycle, *application,* a student finds new uses for the concepts or skills he/she has learned in the Concept Introduction. The application of momentum conservation to automobile collisions or sports would be an appropriate *application* activity to follow the introduction of momentum and its conservation. Other *application* activities could involve the theoretical analysis of the motion of objects that move apart after an interaction. The *application* phase provides additional time and experiences for meaningful learning to take place. It also gives you the opportunity to introduce the new concept repeatedly to help students whose conceptual reorganization proceeds more slowly than average or who did not adequately relate your original explanation to their experiences. Individual conferences with these students to identify their difficulties are especially helpful.

As another example of the learning cycle, we direct your attention to this essay. We did not begin it with a definition of the learning cycle, but rather tried to place you in a situation of considering alternative teaching strategies according to your own experience and preferences, to be compared with our thoughts. That served as *exploration* the best we could think of in the context of this module. Next we described the three-phase learning cycle, the *concept introduction* in this essay, with references to your exploratory experience with the optics example. Finally, we would like you to examine, after the conclusion of this workshop, our entire workshop plan, which is also formulated according to a learning cycle. That examination will form an *application* activity for you, we hope!

Application

1. Return to your notes about the measurement of forces in the exploration which began this module. Sketch possible concept introduction and application phases which could follow this exploration. Discuss your ideas with other members of your group.

2. In 1995 Anton Lawson addressed the issue of whether computer-based activities could be used as exploration and application activities. He stated, "Science requires contact with nature, so the new technologies are unlikely ever to replace the hands-on activities of learning cycles." [*Science Teaching and the Development of Reasoning* (Wadsworth Publishing Co., Belmont, CA, 1995. p.310)]
   Do you agree with Lawson's statement? Discuss your thoughts with your group.

In a physics course for future elementary school teachers, Dean Zollman uses guided explorations and applications. On the following pages are examples for the conservation of momentum. The students write their answers on the pages. In this version, the space of answers has been decreased to save paper.

EXPLORATION 3

INTERACTIONS AND MOMENTUM
I. COLLISIONS

After completing this activity you should be able to:
1. Describe the speed changes when a moving object hits an identical object which is not moving,
2. Describe the speed changes when a moving object strikes an object (not identical) which is not moving.
3. Describe the results when a moving object hits and sticks to an object which is not moving.

So far we have looked at objects in isolation. While we have determined their speeds and positions, we have not considered what happens when one object meets another. If nothing ever met anything else, it would be a dull world. So for the rest of this course, we will look at various types of **interactions** between objects. One particularly interesting interaction is the collision of two objects.

At Station IM-1 is a device which has five small balls suspended by strings. Pull back and release one of the end balls. Describe what happens.

How can you make two balls come off of the end opposite to the end where you release?

Three?

Four?

Is there any way you can pull back and release one ball on the right and get two or more to come off the left?

Can you state a general rule which relates the number of balls which begin swinging on the right with the number which come off on the left?

Just by looking at them can you compare the speeds of the balls going in on the right with the speeds of the ball coming off on the left?

At Station IM-2 is a billiard ball suspended on a string. By placing another ball on the paper cup it can be put in position to collide with the suspended ball. Create collisions for each of the balls at the Station. Describe what happens to the speed of each ball when the billiard ball collides

with another billiard ball?

with the Styrofoam ball?

with the lead ball?

Pick two other objects at the station and predict what will happen to the object when the billiard ball strikes it.

Object ______________________ Prediction:

Object ______________________ Prediction:

Try it. Were your predictions correct? ____________________

At Station IM-3 are low-friction carts and a track. Inside one end of each cart are magnets that cause the carts to repel. Use the magnet ends first. Place one cart at the center of the track so that it is not moving (or is moving *very* slowly). *Gently* push another cart that is identical in size toward the first.

Describe the motion of each cart after the collision. (Include a comparison of speeds before and after the collision.)

Repeat the experiment but use the ends with Velcro so that the carts stick together. Describe the motion after the collision. (Include a comparison of speeds before and after the collision.)

Now place extra mass (black bar) on the cart that is stationary before the collision. Create a collision in which the carts bounce off each other. Describe motion before and after the collision.

Then create a collision in which the cart with extra mass sticks to another cart. Describe the results. In these collisions what are the important variables in determining the speed of each cart after the collision?

At Station IM-4 are similar carts except those carts have small spring plungers that can be released. Place the carts in the middle of the track with the plungers touching each other. Release one plunger and describe the motion.

Add mass to one cart. How does the motion change from the previous case?

Add the same amount of mass to both carts. Describe the motion for this situation.

In what ways is the motion similar on all activities IM-1 to IM-4?

In what ways is the motion different on all activities IM-1 to IM-4?

In class we will put this information together and discuss some general statements about collisions.

Notes for the Concept Introduction

The concept introduction occurs in a large class setting with demonstrations and "clickers" for the students to respond to questions. The notes below are Dean's guide for conducting the class.

Interactions
- Anytime a change takes place an interaction occurs
- What types of changes do you see everyday
  - Speed
  - Shape
  - Temperature
  - Light intensity
  - etc.

Exploration
- Questions to address today
  - Did you see any pattern to the changes?
  - Can you imply any types of interactions from these patterns?

General method for understanding interactions and changes
- Observe changes
- Look for patterns in the changes
- Look for interactions which could account for the changes
- Determine the underlying principles which govern the interactions
- Changes --> patterns --> interactions --> principles

Conservation principles
- One way to look for patterns is to look for quantities which do not change
  - Water is conserved when poured from one container to the next
- Conservation means something which does not change during an interaction
  - Understanding conservation is acquired
    - Matter conservation usually is understood at about age 6 or 7
    - More abstract ideas (such as the ones we will study) come slowly.

Conservation during the exploration
- **Clicker**: Was speed conserved in the interactions in the exploration?
  1. speed was conserved in every interaction
  2. speed was conserved in some but not every interaction
  3. speed was never conserved in the interactions
  4. I don't know

- Try speed on air track
  - OK in equal mass collision
  - Not OK in an explosion
  - Not OK when masses unequal

- Velocity
- **Clicker**: Was velocity conserved in the interactions in the exploration?
  1. velocity was conserved in every interaction
  2. velocity was conserved in some but not every interaction
  3. velocity was never conserved in the interactions
  4. I don't know

  - OK in an explosion with equal masses
  - Not OK with unequal masses
  - Not OK in inelastic collisions

Define Momentum = mass x velocity

Clicker I move with a velocity of (3m/s, east). My mass is 75 kg. What is my momentum?

1. (0.04 kg m/s, east)
2. (25 kg m/s, east)
3. (75 kg m/s, east)
4. (225 kg m/s, east)
5. None of the above
6. I don't know

Work (is conserved) in all these situations
Conserved in all interactions which you considered
Not conserved when interactions from the outside are considered

Conservation of Momentum

Momentum is conserved in a closed system.
Or, in a closed system momentum does not change.
Vector sum of all momenta before an interaction is equal to vector sum of all momenta after the collision

Example: Explosion
Mass = .25 kg
Clicker: What is the magnitude of the total momentum of the two gliders before the explosion?

1. 0
2. (0.25 kg m/s, north)
3. (0.25 kg m/s, south)
4. None of the above
5. Cannot determine from the information given
6. I don't know

Clicker: After the explosion each glider is moving at about 1 m/s. What is the magnitude of momentum of the total two gliders after the explosion?

1. 0
2. (0.25 kg m/s, north)
3. (0.25 kg m/s, south)
4. None of the above
5. Cannot determine from the information given
6. I don't know

Inelastic collision

Clicker: A linebacker with a mass of 150 kg is running east directly at a quarterback with a mass of 100 kg and running west. They collide and stick together. Which direction are they moving directly after the collision?

1. North
2. South
3. East
4. West
5. Some other direction
6. I don't know

Warning to students: In the application "because momentum is conserved" is not sufficient. Explain in detail. "Momentum before was ..., momentum after was ... therefore...."

INTERACTION AND MOMENTUM
II. MOSTLY EXPLOSIONS

APPLICATION 3

After completing this activity you should be able to apply the principle of momentum conservation to
1. explain the motion of the five pendulum balls;
2. explain the motion resulting from a collision;
3. explain the motion resulting from an explosion;
4. determine how an event occurred.

To begin, calculate the magnitude of your momentum for your normal walking speed. Measure your mass at Station IM-5, and then calculate your walking speed by collecting appropriate measurements.

To apply momentum conservation return to the five pendulum balls, now at Station IM-6. Observe the motions again. Using momentum conservation explain why the balls move the way they do when you pull back and release one ball.

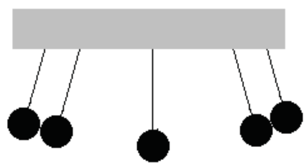
Using momentum conservation explain why two balls come out if two go in; three come out, three go in; etc.

Suppose that, when two go in, one came out at twice the speed of the incoming ball. Would that satisfy momentum conservation as well as two balls out?

Did you ever observe this to happen?

We will discuss this situation further in a few weeks.

Using momentum conservation **predict** what would happen if on the device at Station IM-6 you pulled back and released two balls as shown below.



PREDICTION:

Use momentum conservation to explain your prediction.

Test your prediction. If the result does not agree with the prediction, describe how you need to change your reasoning to apply conservation of momentum to this situation.

Another set of interactions is shown in the video sequence at station IM-7. The scenes were recorded during the Skylab space missions in the 1970s. View each of these scenes and then answer the questions about them.

The first three scenes (IM-7a, 7b and 7c) show collisions of water drops as they occur in space.

Describe the motion in terms of the velocities before and after each collision.
Drop collision 1:

Drop collision 2:

Drop collision 3:

Use conservation of momentum to explain your observations.

Now view the collisions of astronauts (IM 7d, 7e and 7f)

Astronauts: Again, describe the motion before and after each collision.
Collision 1:

Collision 2:

Collision 3:

Can you use conservation of momentum to explain the motion after these collisions? If yes, do it; if no, why not?

We can also apply conservation of momentum to explosions. A safe, simple explosion involves the spring-loaded "roller skates" at Station IM-8. Push the spring-loaded rod into the cart. *Set the carts together with the spring loaded rod of one cart towards the other cart*. *Before releasing the spring* predict the result.
Prediction:

Explain your prediction in terms of momentum conservation before releasing the spring of the cart.

Now do the experiments. If your predictions are different from your results, explain the results in terms of momentum conservation. (Get help from the assistant if you need it.)
Result:

Now load one of the carts with a brick. Predict which cart will have the higher velocity and explain your prediction in terms of momentum conservation.
Prediction:

Test your predictions by determining the speeds of each cart.

Predict what will happen to the speeds if one cart is holding two bricks and the other has none.

Explain your prediction in terms of momentum conservation.

Try it. Was your prediction correct?

At Station IM-9 place one of the carts with the spring end next to a wall. Release the spring. What is the motion of the cart?

What is the system for which momentum is conserved?

Can you explain your observations in terms of momentum conservation?

A frequent question in courses like Engineering Physics goes something like this:

You are lying in bed and want to shut the door to your room without getting up. You happen to have a lump of clay and a rubber ball to throw at the door. Which one is more likely to cause the door to close when you throw it at the door?
At IM-10 you can test your ideas about this situation. However, we will do the experiment a little more carefully than an engineer might. Use the billiard ball on a string. Pull it back a set distance and let it hit the suspended piece of wood. Then put a piece of Play Dough with the same mass as the ball on a string. Pull it back the same distance and let it hit the wood. Describe the differences in the motion of the wood.

Can you explain this result in terms of momentum conservation?

At IM-11 is a video of an ice skater throwing a bowling ball (Strange thing for an ice skater to do). The bowling ball has a mass of 5 kilograms, but we don't know the mass of the skater. Because of the camera angle we cannot measure the speeds of the bowling ball and the skater. Suppose you could make the measurement. Describe how you can determine the mass of the skater from these data and the conservation of momentum.

Just look at the event and try to estimate her approximate mass?

At Station IM-12 is another video of some ice skating. In this one the skaters are performing synchronized skating routine. Watch as some skaters move forward in the group. What happens to the speed of the skaters who *do not* move forward?

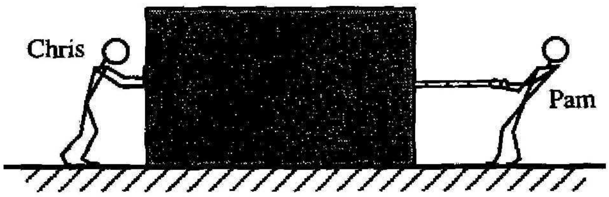
Use conservation of momentum to explain these observations.

On Friday, we will continue the discussion of momentum conservation.

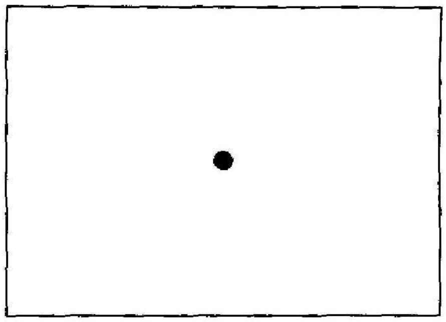
FORCES

I. Free-body diagrams

Two people are attempting to move a large block. The block, however, does not move. Chris is pushing on the block. Pam is pulling on a rope attached to the block.



Copy your group's sketch here after discussion.



A. Draw a large dot on your large sheet of paper to represent the block. Draw vectors with their "*tails*" on the dot to show the forces exerted *on* the block. Label each vector and write a brief description of that force next to the vector.

In Newtonian physics, all forces arise from an interaction between *two* objects. Forces are specified by identifying the object *on which* the force is exerted and the object *that is exerting* the force. For example, in the situation above, a gravitational force is exerted *on* the block *by* the earth.

B. Describe the remaining forces you have indicated above in a similar fashion.

The diagram you have drawn is called a *free-body diagram.* A free-body diagram should show only the forces exerted *on* the object or system of interest, that is, in this case, *on the block.* Check your free-body diagram and, if necessary, modify it accordingly.

Sometimes a free-body diagram involves a simplified sketch of the object rather than the dot. (Your instructor will indicate the convention you are to use.) Regardless of which form is used, a proper free-body diagram should *not* have anything on it except a representation of the object and the (labeled) forces exerted on that object. A free-body diagram *never* includes (1) forces exerted by the object of interest on other objects or (2) sketches of other objects that exert forces on the object of interest.

C. All forces arise from interactions between objects, but the interactions can take different forms.

Which of the forces exerted on the block require *direct contact* between the block and the object exerting the force?

Which of the forces exerted on the block *do not* arise from direct contact between the block and the object exerting the force?

We will call forces that depend on contact between two objects *contact forces.* We will call forces that do not arise from contact between two objects *non-contact forces.*

D. There are many different types of forces, including: friction ($\vec{f}$), tension ($\vec{T}$), magnetic forces ($\vec{F}^{mag}$), normal forces ($\vec{N}$), and the gravitational force ($\vec{W}$, for weight). Categorize these forces according to whether they are contact or non-contact forces.

Contact forces	Non-contact forces

E. Consider the following discussion between two students.

Student 1: *"I think the free-body diagram for the block should have a force by Chris, a force by the rope, and a force by Pam."*

Student 2: *"I don't think the diagram should show a force by Pam. People can't exert forces on blocks without touching them."*

With which student, if either, do you agree? Explain your reasoning.

It is often useful to label forces in a way that makes clear (1) the type of force, (2) the object on which the force is exerted, and (3) the object exerting the force. For example, the gravitational force exerted *on* the block *by* the earth might be labeled $\vec{W}_{BE}$. Your instructor will indicate the notation that you are to use.

F. Label each of the forces on your free-body diagram in part A in the manner described above.

➪ Do not proceed until a tutorial instructor has checked your free-body diagram.

II. Forces

A. Sketch a free-body diagram for a book at rest on a level table. (*Remember:* A proper free-body diagram should not have anything on it except a representation of the book and the forces exerted *on* the book.)

Make sure the label for each force indicates:

- the type of force (gravitational, frictional, *etc.*),
- the object on which the force is exerted, and
- the object exerting the force.

1. What evidence do you have for the existence of each of the forces on your diagram?

2. What observation can you make that allows you to determine the relative magnitudes of the forces acting on the book?

   How did you show the relative magnitudes of the forces on your diagram?

B. A second book of greater mass has been placed on top of the first.

Sketch a free-body diagram for each of the books in the space below. Label all the forces as in part A.

Free-body diagram for upper book	Free-body diagram for lower book

Specify which of the forces are contact forces and which are non-contact.

1. Examine all the forces on the two free-body diagrams you just drew. Explain why a force that appears on one diagram *should not* appear on the other diagram.

2. What *type* of force does the upper book exert on the lower book (*e.g.*, frictional, gravitational)?

   Why would it be *incorrect* to say that the weight of the upper book acts on the lower book?

3. What observation can you make that allows you to determine the relative magnitudes of the forces on the *upper* book?

4. Are there any forces acting on the *lower* book that have the same magnitude as a force acting on the *upper* book? Explain.

C. Compare the free-body diagram for the lower book to the free-body diagram for the same book in part A (*i.e.*, before the upper book was added).

   Which of the forces changed when the upper book was added and which remained the same?

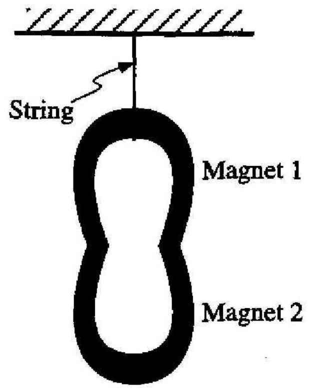
As discussed earlier, we think of each force acting on an object as being exerted by another object. The first object exerts a force of equal magnitude and opposite direction on the second object. The two forces together are called an *action-reaction* or *Newton's third law* force pair.

D. Which, if any, Newton's third law force pairs are shown in the diagrams you have drawn? On which object does each of the forces in the pair act?

   Identify any third law force pairs on your diagrams by placing a small "×" through each member of the pair. For example, if you have two sets of third law force pairs shown on your diagrams, mark *each* member of the first pair as —X▶, and each member of the second pair as —XX▶.

III. Supplement: Contact and non-contact forces

A. A magnet is supported by another magnet as shown at right.



1. Draw a free-body diagram for magnet 2. The label for each of the forces on your diagram should indicate:
   - the type of force (*e.g.*, gravitational, normal),
   - the object on which the force is exerted, and
   - the object exerting the force.

2. Suppose that the magnets were replaced by stronger magnets of the same mass.

   If this changes the free-body diagram for magnet 2, sketch the new free-body diagram and describe how the diagram changes. (Label the forces as you did in part 1 above.) If the free-body diagram for magnet 2 does not change, explain why it does not.

3. Can a magnet exert a non-contact force on another object?

   Can a magnet exert a contact force on another object?

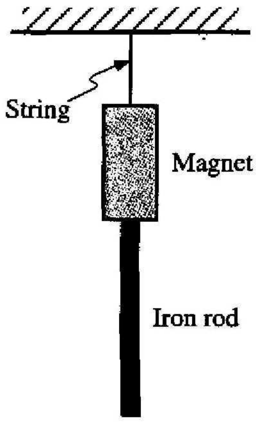
   Describe how you can use a magnet to exert *both* a contact force and a non-contact force on another magnet.

4. To ensure that you have accounted for all the forces acting on magnet 2 in parts 1 and 2:

   List all the non-contact forces acting on magnet 2.

   List all the contact forces acting on magnet 2. (*Hint:* Which objects are in *contact* with magnet 2?)

B. An iron rod is held up by a magnet as shown. The magnet is held up by a string.



1. In the spaces below, sketch a free-body diagram for the iron rod and a separate free-body diagram for the magnet.

   The label for each of the forces on your diagrams should indicate:

   - the type of force (*e.g.*, gravitational, normal),
   - the object on which the force is exerted, and
   - the object exerting the force.

Free-body diagam for iron rod	Free-body diagam for magnet
(*Hint:* There should be three forces.)	(*Hint:* There should be four forces.)

2. For each of the forces shown in your diagram for the iron rod, identify the corresponding force that completes the Newton's third law (or action-reaction) force pair.

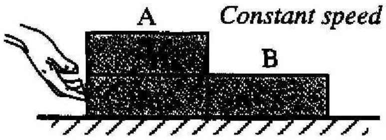
3. How would your diagram for the iron rod change if the magnet were replaced with a stronger magnet? Which forces would change (in type or in magnitude)? Which forces would remain the same?

NEWTON'S SECOND AND THIRD LAWS

I. Interacting objects: constant speed

Three identical bricks are pushed across a table at *constant speed* as shown. The hand pushes horizontally. (*Note:* There is friction between the bricks and the table.)

Call the stack of two bricks system A and the single brick, system B.



A. Describe the motions of systems A and B.

B. Compare the *net force* (magnitude and direction) on system A to that on system B. Explain how you arrived at your comparison.

C. Draw separate free-body diagrams for system A and system B. Label each of the forces in your diagrams by identifying: the type of force, the object on which the force is exerted, and the object exerting the force.

Free-body diagram for system A	Free-body diagram for system B

D. Is the magnitude of the force exerted on system A by system B *greater than, less than,* or *equal to* the magnitude of the force exerted on system B by system A? Explain.

Would your answer change if the hand were pushing system B to the left instead of pushing system A to the right? If so, how? If not, why not?

E. Identify any *Newton's third law* (or *action-reaction*) force pairs you have drawn using the convention introduced in the *Forces* tutorial, that is, by placing a small "×" through each member of the pair.

What criteria did you use to identify the force pair(s)?

Is your answer to part D consistent with your identification of Newton's third law (or action-reaction) force pairs? If so, explain how it is consistent. If not, resolve the inconsistency.

F. Rank the magnitudes of all the *horizontal* forces that you identified on your free-body diagrams in part C. (*Hint:* Recall that the bricks are pushed so that they move at constant speed.)

Did you apply Newton's second law in comparing the magnitudes of the horizontal forces? If so, how?

Did you apply Newton's third law in comparing the magnitudes of the horizontal forces? If so, how?

What information besides Newton's laws did you need to apply in comparing the magnitudes of the horizontal forces?

G. Suppose the mass of each brick is 2.5 kg, the coefficient of kinetic friction between the bricks and the table is 0.2, and the bricks are moving at a constant speed of 0.50 m/s.

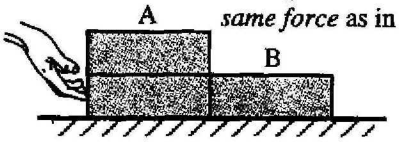
Determine the magnitude of each of the forces that you drew on your free-body diagrams in part C. (Use the approximation $g = 10\ \text{m/s}^2$.)

Would your answers change if the bricks were moving half as fast? If so how? If not, why not?

⇨ Discuss your answers with a tutorial instructor before continuing.

II. Interacting objects: varying speed

Suppose the bricks were pushed by the hand with the same force as in section I; however, the coefficient of kinetic friction between the bricks and the table is *less than* that in section I.



A. Describe the motions of systems A and B.

B. Compare the *net force* (magnitude and direction) on system A to that on system B. Explain.

C. Draw and label separate free-body diagrams for systems A and B.

Free-body diagram for system A	Free-body diagram for system B

D. Consider the following discussion between two students.

Student 1: *"System A and system B are pushed by the same force as before, so they will have the same motion as in section I."*

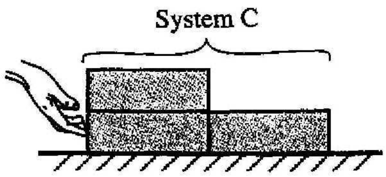
Student 2: *"I disagree. I think that they are speeding up since friction is less. So now system A is pushing on system B with a greater force than system B is pushing on system A."*

With which student, if either, do you agree? Explain your reasoning.

E. Rank the magnitudes of all the *horizontal* forces that appear on your free-body diagrams in part C. Explain your reasoning. (Describe explicitly how you used Newton's second and third laws to compare the magnitudes of the forces.)

Is it possible to *completely* rank the horizontal forces in this case?

III. System of interacting objects



Let C represent the system consisting of all three bricks. The motion of the blocks is the same as in section II.

A. Compare the magnitude of the *net force* on system C to the magnitudes of the *net forces* on systems A and B. Explain.

B. Draw and label a free-body diagram for system C.

Free-body diagram for system C

Compare the forces that appear on your free-body diagram for system C to those that appear on your diagrams for systems A and B in section II.

For each of the forces that appear on your diagram for system C, list the corresponding force (or forces) on your diagrams for systems A and B.

Are there any forces on your diagrams for systems A and B that you did not list? If so, what characteristic do these forces have in common that none of the others share?

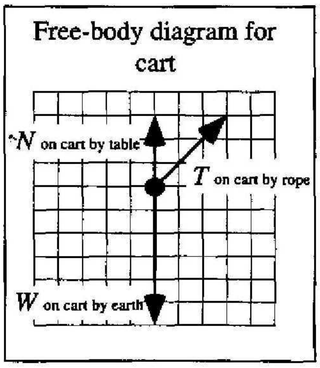
Why is it not necessary to consider these forces in determining the motion of system C?

Note that such forces are sometimes called *internal forces,* to be distinguished from *external forces.*

IV. Application of Newton's laws

At right is a free-body diagram for a cart. All forces have been drawn to scale.

In the space below, sketch the cart, rope, *etc.*, as they would appear in the laboratory.

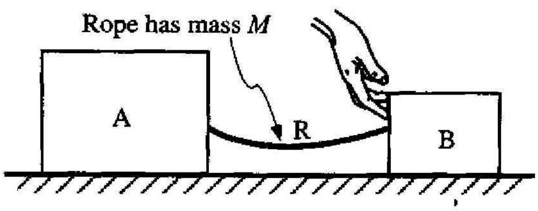


What can you say about the motion of the cart based on the free-body diagram? For example, could the cart be: moving to the left? moving to the right? stationary? Explain whether each case is possible and, if so, describe the motion of the cart.

TENSION

I. Blocks connected by a rope

Two blocks, A and B, are tied together with a rope of mass *M*. Block B is being pushed with a constant horizontal force as shown at right. Assume that there is no friction between the blocks and the table and that the blocks have already been moving for a while at the instant shown.



A. Describe the motions of block A, block B, and the rope.

B. Draw a separate free-body diagram for each block and for the rope. Clearly label the forces.

Copy your free-body diagrams here after discussion.

Free-body diagram for block A	Free-body diagram for rope	Free-body diagram for block B

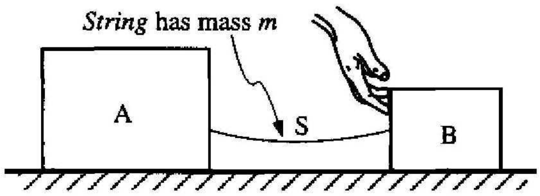
C. Identify all the *Newton's third law (action-reaction)* force pairs in your diagrams by placing a small "×" through each member of the pair (*i.e.,* mark each member of the first pair as —×▶, each member of the second pair as ××▶, and so on).

D. Compare the magnitudes of the *horizontal components* of all forces on your diagrams. If any of the forces have the same magnitude, state that explicitly. Explain the reasoning you used to arrive at this comparison.

E. Consider the horizontal components of the forces exerted *on the rope* by blocks A and B. Is your answer above for the relative magnitude of these components consistent with your knowledge of the net force on the rope?

II. Blocks connected by a very light string

The blocks in section I are now connected with a very light, flexible, and inextensible string of mass *m* (*m* < *M*).



A. If the motion of the blocks is the same as in section I, how does the net force on the *string* compare to the net force on the *rope?*

Determine whether the net force on the following objects is *greater than, less than,* or *equal to* the net force on them in section I: block A, block B, and the system composed of the blocks and the connecting rope or string. Explain.

Compare the horizontal components of the following pairs of forces:

- the force on the string by block A and the force on the rope by block A. Explain.

- the force on the string by block B and the force on the rope by block B. Explain.

B. Suppose the mass of the string that connects blocks A and B becomes smaller and smaller, but the motion remains the same as in section I. What happens to:

- the magnitude of the net force on that connecting string?

- the magnitudes of the forces exerted on that connecting string by blocks A and B?

C. A string exerts a force on each of the two objects to which it is attached. For a massless string, the magnitudes of both forces are often referred to as "the tension in the string."

Justify the use of this terminology, in which a *single value* is assumed for the magnitudes of both forces.

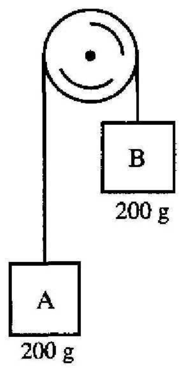
D. If you know that the net force on a massless string is zero, what can you infer about its motion?

Is it possible to exert a non-zero force on a massless string? Is it possible for a massless string to have a non-zero *net* force? Explain.

➪ Discuss your answers above with a tutorial instructor before continuing.

III. The Atwood's machine

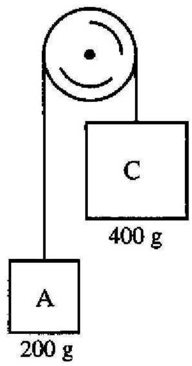
The Atwood's machine at right consists of two identical objects connected by a massless string that runs over an ideal pulley. Object B is initially held so that it is above object A and so that neither object can move.



A. Predict the subsequent motions of objects A and B after they are released. Explain the basis for your description. Do not use algebra.

B. Draw separate free-body diagrams for objects A and B. Are your free-body diagrams consistent with your prediction of the motion of the objects?

Object B is replaced by object C, of greater mass. Object C is initially held so that it is higher than object A and so that neither object can move.



C. *Predict:*

- what will happen to object C when it is released.
- how the motion of object C will compare to the motion of object A after they are released.

Explain the basis for your predictions. Do not use algebra.

D. Draw and label separate free-body diagrams for objects A and C *after* they are released. Indicate the relative magnitudes of the forces by the relative lengths of the force vectors.

Are the predictions you made in part C consistent with your free-body diagrams for objects A and C? If so, explain why they are consistent. If not, then resolve the inconsistency.

E. The weight of a 200 g mass has magnitude (0.2 kg)(9.8 m/s^2) ≈ 2 N. Similarly, the weight of a 400 g mass is approximately 4 N in magnitude.

1. How does the force exerted on object A by the string compare to these two weights?

2. How does the force exerted on object C by the string compare to these two weights?

   Explain your answers.

3. How does the net force on object A compare to the net force on object C? Explain.

F. Consider the following statement about the Atwood's machine made by a student.

> *"All strings can do is transmit forces from other objects. That means that the string in the Atwood's machine just transmits the weight of one block to the other."*

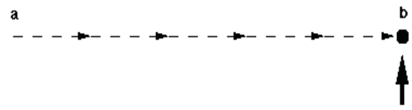
Do you agree with this student? Explain your reasoning.

Below are some questions about forces. Answer the questions below as you think your students would answer them. Below each question write the reasons that you chose the answer that you did.

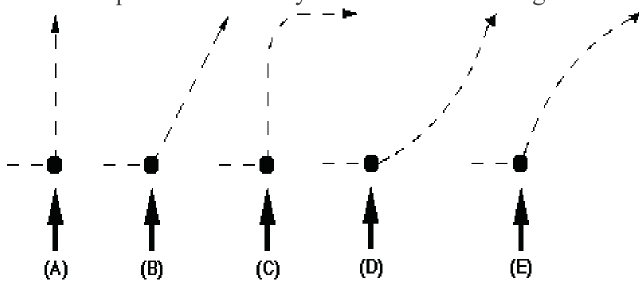
1. A large truck collides head-on with a small compact car. During the collision:
   (A) the truck exerts a greater amount of force on the car than the car exerts on the truck.
   (B) the car exerts a greater amount of force on the truck than the truck exerts on the car.
   (C) neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
   (D) the truck exerts a force on the car but the car does not exert a force on the truck.
   (E) the truck exerts the same amount of force on the car as the car exerts on the truck.

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT FOUR QUESTIONS (2 through 5).

The figure depicts a hockey puck sliding with constant speed v_o in a straight line from point "a" to point "b" on a frictionless horizontal surface. Forces exerted by the air are negligible. You are looking down on the puck. When the puck reaches point "b," it receives a swift horizontal kick in the direction of the heavy print arrow. Had the puck been at rest at point "b," then the kick would have set the puck in horizontal motion with a speed vk in the direction of the kick.



2. Which of the paths below would the puck most closely follow after receiving the kick ?

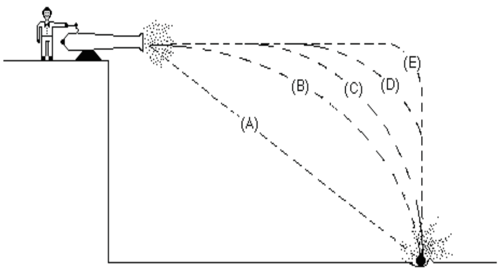


3. The speed of the puck just after it receives the kick is:
   (A) equal to the speed "v_o" it had before it received the kick.
   (B) equal to the speed "v_k" resulting from the kick and independent of the speed "v_o".
   (C) equal to the arithmetic sum of the speeds "v_o" and "v_k".
   (D) smaller than either of the speeds "v_o" or "v_k".
   (E) greater than either of the speeds "v_o" or "v_k", but less than the arithmetic sum of these two speeds.

4. Along the frictionless path you have chosen in question 2, the speed of the puck after receiving the kick:
(A) is constant.
(B) continuously increases.
(C) continuously decreases.
(D) increases for a while and decreases thereafter.
(E) is constant for a while and decreases thereafter.

5. Along the frictionless path you have chosen in question 2, the main force(s) acting on the puck after receiving the kick is (are):
(A) a downward force of gravity.
(B) a downward force of gravity, and a horizontal force in the direction of motion.
(C) a downward force of gravity, an upward force exerted by the surface, and a horizontal force in the direction of motion.
(D) a downward force of gravity and an upward force exerted by the surface.
(E) none. (No forces act on the puck.)

6. A ball is fired by a cannon from the top of a cliff as shown in the figure below. Which of the paths would the cannon ball most closely follow?



7. A boy throws a steel ball straight up. Consider the motion of the ball only after it has left the boy's hand but before it touches the ground, and assume that forces exerted by the air are negligible. For these conditions, the force(s) acting on the ball is (are):
(A) a downward force of gravity along with a steadily decreasing upward force.
(B) a steadily decreasing upward force from the moment it leaves the boy's hand until it reaches its highest point; on the way down there is a steadily increasing downward force of gravity as the object gets closer to the earth.
(C) an almost constant downward force of gravity along with an upward force that steadily decreases until the ball reaches its highest point; on the way down there is only a constant downward force of gravity.
(D) an almost constant downward force of gravity only.
(E) none of the above. The ball falls back to ground because of its natural tendency to rest on the surface of the earth.

Below are some questions about forces. Answer the questions below as you think your students would answer them. Below each question write the reasons that you chose the answer that you did.

1. Imagine a head-on collision between a very full shopping cart and an empty cart. Both carts are moving very quickly. During the collision,

(A) the full cart exerts a greater amount of force on the empty cart than the empty cart exerts on the full cart.

(B) the empty cart exerts a greater amount of force on the full cart than the full cart exerts on the empty cart.

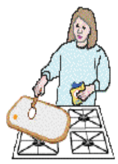
(C) neither exerts a force on the other, the empty cart gets smashed simply because it gets in the way of the full cart.

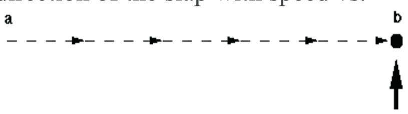
(D) the full cart exerts a force on the empty cart but the empty cart doesn't exert a force on the full cart.

(E) the full cart exerts the same amount of force on the empty cart as the empty cart exerts on the full cart.

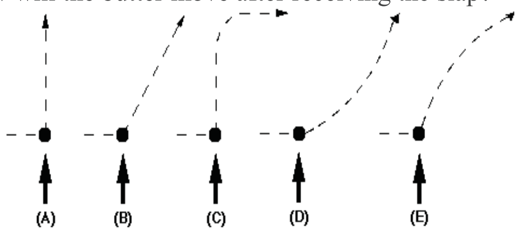
USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT FOUR QUESTIONS (2 through 5).

The diagram below shows a pat of butter sliding with a constant speed v_o along a hot griddle (as observed from directly above). The butter slides in a straight line from point “a” to point “b” along this frictionless horizontal surface. You are looking down on the griddle. When the butter reaches point “b,” it is given a quick horizontal slap with a spatula in the direction of the heavy arrow. If the butter had not been moving when the spatula slapped it, then the spatula would have sent the butter moving in the direction of the slap with speed vs.





2. Along which of the paths below will the butter move after receiving the slap?



3. The speed of the butter just after it receives the quick slap is:

(A) Equal to the speed "v_o" it had before it received the slap.

(B) Equal to the speed "v_s" resulting from the slap, and independent of the speed "v_o".

(C) Equal to the arithmetic sum of speeds "v_o" and "v_s".

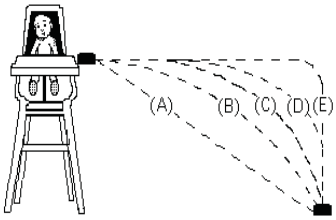
(D) Smaller than either of speeds "v_o" or "v_s".

(E) Greater than either of the speeds "v_o" or "v_s", but smaller than the arithmetic sum of these two speeds.

4. Along the frictionless path you have chosen in question 8, the speed of the butter after receiving the slap:
(A) is constant.
(B) continuously increases.
(C) continuously decreases.
(D) increases for a while, and decreases thereafter.
(E) is constant for a while, and decreases thereafter.

5. Along the frictionless path you have chosen in question 2, the main force(s) acting on the butter after receiving the slap is (are):
(A) the downward force of gravity.
(B) the downward force of gravity and a horizontal force in the direction of motion.
(C) the downward force of gravity, the upward force exerted by the griddle, and a horizontal force in the direction of motion.
(D) the downward force of gravity and an upward force exerted by the griddle.
(E) none. (No forces act on the butter.)

6. A baby in a high chair slides her bowl of food horizontally off the side of her flat tray with a quick push. Which path below best represents the path of the bowl?



13. A girl throws a teddy bear straight up. Consider the motion of the bear only after it has left the girl's hand but before it touches the ground, and assume that forces exerted by the air are negligible. For these conditions, the force(s) acting on the bear is (are):
(A) a downward force of gravity along with a steadily decreasing upward force.
(B) a steadily decreasing upward force from the moment it leaves the girl's hand until it reaches its highest point; on the way down there is a steadily increasing downward force of gravity as the bear gets closer to the earth.
(C) an almost constant downward force of gravity along with an upward force that steadily decreases until the bear reaches its highest point; on the way down there is only a constant downward force of gravity.
(D) an almost constant downward force of gravity only.
(E) none of the above. The bear falls back to the ground because of its natural tendency to rest on the surface of the earth.

ADAPTED FROM WORKSHOP PHYSICS UNIT 5: ONE-DIMENSIONAL FORCES, MASS, AND MOTION

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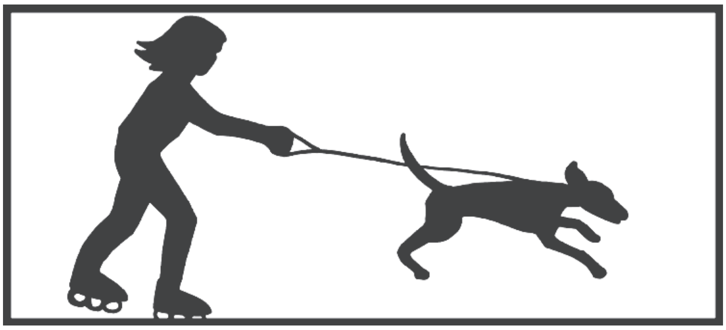
The Apollo/Saturn V space vehicle carrying Apollo 11 astronauts Neil A. Armstrong, Michael Collins, and Edwin E. Aldrin, Jr., lifted off at 9:32 A.M. EDT on July 16, 1969. This was our nation's first manned lunar landing mission. The 36-foot-high vehicle generated a thrust of seven and one-half million pounds during liftoff. It lumbered off the launch pad very slowly at first, and then picked up speed rapidly. Its velocity may have increased at slightly more than a constant rate during the early stages of take off. This increasing acceleration was probably followed by a decreasing acceleration even if the ejected fuel created a constant thrust force on the rocket. Yet, the rocket's motion and escape from the Earth's gravitational attraction happened in accordance with Newton's Laws of motion. How is it possible for the rocket to give itself a constant thrust force and have an acceleration that is not constant? As you study the fundamental relationships between one-dimensional net force, mass, and motion in this unit, you should be able to answer this question.

UNIT 5: ONE-DIMENSIONAL FORCES, MASS, AND MOTION



If you find the study of motion difficult, reflect that it took mankind . . . over sixteen hundred years to reach a clear understanding of motion; you should hardly be impatient if it takes you several weeks.

Eric Rogers (1961)

No one must think that Newton's great creation [the three laws of motion] can be overthrown. . . . His clear and wide ideas will forever retain their significance as the foundation on which our modern conceptions of physics have been built.

Albert Einstein (1948)

OBJECTIVES

1. To devise a method for applying a constant force to an object.

2. To find a mathematical relationship between force and motion.

3. To devise a force scale to measure one, two, three, etc. units of force.

4. To understand how different one-dimensional forces acting along the same line can be combined.

5. To develop a definition of mass in terms of an object's motion under the influence of a known force.

6. To combine all of the observations and develop statements of *Newton's First and Second Laws of Motion* for one-dimensional motion with very little friction present.

5.1 OVERVIEW

So far in your study of one dimensional motion you have learned to observe and describe motion in several ways. The next step is to study the causes of motion.

The motion of an object is obviously influenced by pushes or pulls, electrical or magnetic attractions, winds, and so on. Even casual observations tell us that the way an object that is pushed or pulled moves depends on the "amount of stuff" it is made of. It's easier to push a shopping cart than a Mack truck. In physics we usually refer to a push or pull as a *force*, while we refer to the "amount of stuff" as the *mass* of an object. In this unit you will explore intuitive ideas of force and mass, and study the influence of force on motion. Finally, you will formulate two laws of motion developed by Isaac Newton in the seventeenth century.

Fig. 5.1.

Newton's Laws of motion are powerful! When forces on a system are known, Newton's Laws can be used to describe or predict its behavior.* This predictive ability is of tremendous importance to engineers who want to design bridges that don't collapse and cars that stop reliably. Also, a belief in the Laws of Motion allows scientists to deduce the nature of fundamental forces such as intergalactic forces and nuclear forces on the basis of observations of motions. As Newton stated,

> . . . the phenomena of motions [can be used] to investigate the forces of Nature, and then . . . these forces [can be used] to demonstrate other phenomena...the motions of the planets, the comets, the moon and the sea.

Note: The classical laws of motion that we will develop in this unit provide for all practical purposes "exact" descriptions of the motions of everyday objects traveling at ordinary speeds. During the early part of the twentieth century two new theories were developed—quantum theory, which describes motion in the atomic realm, and relativity, which describes objects moving extremely fast. Once you master the classical description of ordinary motions, it is exciting indeed to see how these laws are modified so that they will also describe very small objects or objects moving at extraordinary speeds (close to that of light).

* Often when forces are known, the actual position and velocity of the system can be predicted within the limits of experimental uncertainty. However, there are some systems that exhibit chaotic behavior that can be described in terms of well-understood forces but not predicted.

FORCE AND MOTION

5.2 MOTION FROM A CONSTANT FORCE

In your previous study of motion in this course you concentrated on describing motion rather than on understanding its causes. From your experiences, you know that force and motion are related in some way. For example, to start a bicycle moving, you have to push down on the pedals, or to start a wagon moving you have to pull on it. What kinds of forces lead to steady motion? To changes in motion?

Before you can study the relationship between force and motion, you must be able to devise a useful definition of force and develop reliable ways to measure it. Then you can investigate these relationships by applying forces of different strengths to various objects. You can begin by figuring out how to apply a constant force to a person who can slide along a smooth floor or roll along on a low friction cart. Then you can measure the motion of the person under the influence of a constant force using a computer-based laboratory system.

In order to do the activities in this section you will need some but not necessarily all of the following items to investigate the creation of a constant force:

- 1 small spring scale
- 1 large rubber band
- 1 large spring scale
- 1 force measuring device from previous activity

What is force and how is it measured? The word force is a very common part of everyday language. One of the major tasks in this unit is to help you move in stages from an informal understanding of the meaning of the term force as a push or pull to a more precise, quantitative definition that is useful in relating force to motion.

5.2.1. Activity: Ideas about Force

Attempt to define the word force in your own words. What are some examples of forces? How might you measure how large a given force is?

Creating a Constant Force

In order to explore the relationship between force and motion, you should try to figure out how to apply a constant force to an object. You can use any of the equipment listed for this section or any other common items you have available.

5.2.2. Activity: Applying a Constant Force

Devise a method for pulling on an object with a constant force. Explain your method and also explain why you believe that the force is constant.

Predicting Motion from a Constant Pull

Suppose you exert a fairly large constant pull on a person? We are interested in having you track the motion of a person sitting directly on a smooth level floor (or on top of a large garbage bag). Then we would like you to track the motion of a person riding on a bicycle. These situations are shown in Figure 5.2.

Fig. 5.2. Being pulled with a constant force under two circumstances—(a) sliding along a level floor (while sitting on a relatively smooth floor or on a plastic garbage bag) and (b) rolling along a level floor on a low-friction cart.

5.2.3. Activity: Predicting the Velocity of a Person Being Pulled with a Constant Force

a. Consider the situation in Figure 5.2a. What do you predict you might see for a velocity vs. time graph if the person starts from rest and slides along the floor while being pulled with a constant applied force? Sketch the shape of the predicted graph in the space below.

b. Consider the situation in Figure 5.2b. What do you predict you might see for a velocity vs. time graph if the person starts from rest and rolls along the floor while being pulled away from a motion sensor with a constant force? Sketch the shape of the predicted graph in the space below.

c. Explain the reasons for your predictions. If you predict that the two graphs will have the same shape, explain why. If you predict different shapes, explain why you expect the shapes to be different.

Observing Motion from a Constant Pull

You can work with the rest of the class or with one or more partners to create and record the sliding and rolling motions with a constant force. We suggest you use a large rubber band or spring scale stretched out to a constant distance to create a constant pulling force. If the person being pulled holds a meter stick, the puller can try to keep the stretch fairly constant. The person should be pulled away from the motion sensor. These motions take some practice to create. To get reliable measurements, apply enough constant force in each case to get velocities of 0.5 m/s or more for a time period of about 5 seconds.

5.2.4. Activity: Observing the Velocity of a Person Being Pulled with a Constant Force

a. Create the sliding situation depicted in Figure 5.2a and observe what the velocity is as a function of time. Fill in the horizontal and vertical axis values on the following graph frame and sketch the observed graph.

b. Examine the overall shape of the graph for the sliding motion. (Ignore the smaller bumps associated with the wobbling spring or rubber band.) Is the velocity zero, constant, or changing? Is the acceleration zero, constant, or changing? Explain what characteristic of the graph shape supports your description.

c. Explain how you created the constant force. Describe the pulling method used. If you stretched the rubber band or spring, what was the amount of the stretch?

d. Create the one-dimensional rolling situation depicted in Figure 5.2b and observe what the velocity along the *x*-axis is as a function of time. Fill in the horizontal and vertical axis values on the following graph frame and sketch the observed graph.

e. Examine the overall shape of the graph for the rolling motion. (Ignore the smaller bumps associated with the wobbling spring or rubber band.) Is the velocity zero, constant, or changing? Is the acceleration zero, constant, or changing? Explain what characteristic of the graph shape supports your description.

f. How did the observations you reported in a. and d. compare with your predictions?

g. State a general rule based on your observations for the relationship between a constant applied force and velocity when *friction is significant*, for example, when an object slides.

h. State a general rule based on your observations for the relationship between a constant applied force and acceleration when the friction is low.

i. Based on your observed velocity vs. time graph for the low friction rolling motion resulting from a steady pull, sketch an acceleration vs. time graph for the time period during which the pulling force was roughly constant.

Rolling vs. Sliding Motions

You probably observed that a constant force leads to a constant velocity when an object is sliding. On the other hand, a rolling object appears to move at a constant acceleration under the influence of a constant force. This is a surprising observation to most people! The sliding motion involves a significant amount of friction while the rolling does not. In this unit, you will be working with rolling objects that have only a small amount of friction to discover Laws of Motion in the absence of friction. In Unit 6 you will return to the question of how friction can be incorporated into the laws of motion.

5.3 COMBINING EQUIVALENT FORCES

In the last section you should have discovered that a single constant force applied to an object that rolls without much friction causes it to move with a constant acceleration. What happens to the acceleration of a rolling object when the force doubles or triples? What if the force is not constant? What happens to the object's acceleration then?

Before you can proceed with further investigations of the relationship between force and motion, you need to explore reliable ways to measure arbitrary forces. *Being able to produce and combine equivalent forces will enable you to define a force scale and understand how forces of arbitrary strengths can be measured and created.*

We'd like you to work in small groups to investigate how to find equivalent forces and combine them. You will use small low-friction dynamics carts. Thus, you need to learn to work with a smaller force than the one used to pull a student riding on a bicycle.

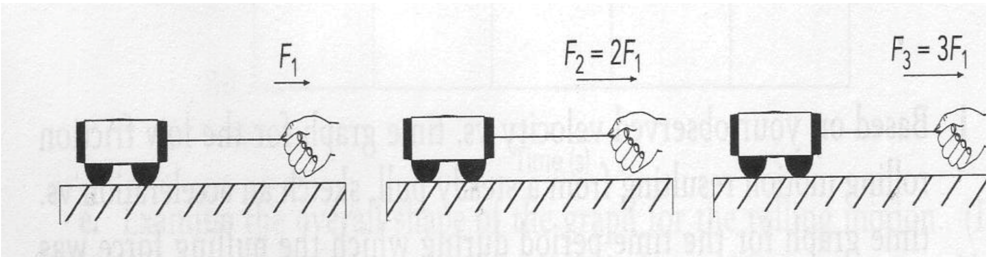


Fig. 5.3. Given a force F_1, how can we apply double or triple that force?

The activities in this section are not completely specified

Equivalent Forces

A way to create double and triple forces is to combine equivalent forces. You should start this investigation by pulling a single rubber band out to some predetermined length that you choose. You can name the unit of force associated with the pull after yourself or make up another name for it.

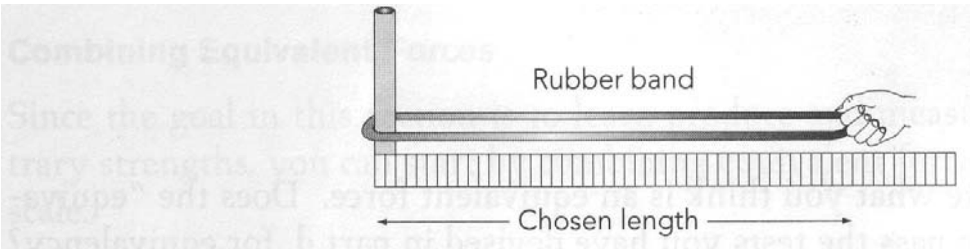


Fig. 5.4. Pulling a rubber band out to a chosen length.

5.3.1. Activity: Creating Equivalent Forces

a. Pick out one of the #14 rubber bands as your standard rubber band. You may want to identify it by marking it with a pen or pencil. Now use your rubber band to define your own unit of constant force. Explain how your unit of force is created. In other words, if you were to give your rubber band to someone else, explain how they could use it to pull on something with your unit of constant force.

b. Consult with your partner(s) and decide what you want to call your unit.

c. Suppose we define an equivalent force as a force that accelerates a cart in exactly the same way that your unit of force does. Consult with your partner(s) and think of as many different techniques as possible to create an *equivalent force* using different objects than your special rubber band. Describe three or more of these techniques.

d. Now consult with your partners and think of two or more ways to test whether a proposed equivalent force is actually equivalent to your force unit.

e. Now create what you think is an equivalent force. Does the "equivalent" force pass the tests you have devised in part d. for equivalency? Explain.

Evaluating Alternatives for Testing Equivalent Forces

Sometimes when there are alternative ways to accomplish a goal some seem better than others. You should discuss your ideas and findings with your classmates and then choose what you think is the best technique for creating a force that is equivalent to your unit in terms of its ability to accelerate a cart in the same way that your force did.

5.3.2. Activity: Equivalent Force Techniques

a. Are there any other tests for equivalency suggested by classmates that you and your partners didn't think of? If so, list them below.

b. Which do you think is the most scientifically sound test for equivalency? Which of the techniques do you prefer to use to create an equivalent force? Why do you prefer it? How do you know it is valid?

Combining Equivalent Forces

Since the goal in this section is to learn produce and measure forces of arbitrary strengths, you can start by combining equivalent forces to create a force scale. Let's assign an x-axis that is parallel to the line of motion you are studying. You can then denote your basic unit of force as F_x.

5.3.3. Activity: Creating F_x, $2F_x$, $3F_x$ . . .

Describe how you could use a batch of essentially identical rubber bands to create forces that have double and triple the strength of your initial force unit.

5.4 USING STANDARD UNITS TO MEASURE FORCE

So far you have been measuring forces in your own units using procedures that you and your partners have defined. If you measure forces and want to have scientists in another location understand your results, it would be convenient if everyone used the same force unit. The accepted standard unit for force is the *Newton*. The Newton is defined as the force that is needed to give a 1 kilogram mass an acceleration in which the velocity of an object increases by 1 meter per second each second. We're getting ahead of ourselves because we haven't defined the kilogram as a unit of mass yet. We will soon.

A scientifically rigorous way to measure a force of 1.0 newtons is to take a 1.0-kg object that can move without friction and apply just the right force to it to get an acceleration of 1.0 m/s/s. That force would, by definition, be one newton—at least to two significant figures. But it is a pain to have to go to all that trouble, and you can use a standard device for measuring force in newtons instead.

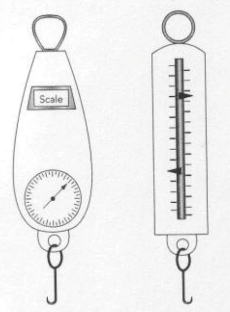


Fig. 5.5. Two types of spring scales used to measure forces in Newtons.

The most common device for measuring forces in newtons consists of a spring with a scale attached to it that is marked off in newtons. In theory, someone already figured out how much the spring has to stretch to get a 1.0 kilogram mass moving with an acceleration of 1.0 m/s/s and combined forces to define the appropriate scale.

Another less common but very useful way to measure force is to use an electronic force sensor attached to a computer-data acquisition system that has been *calibrated* to read in newtons.

In the activities in this section, you will measure forces in newtons with a spring scale

- •1 ruler
- •6 rubber bands, #14
- •1 spring scale, 10 N

Measuring Force in Newtons with a Spring Scale

You should devise a way to use rubber bands to show that the forces indicated on a spring scale in Newtons are proportional to your rubber band units.

5.4.1. Activity: Converting Your Units to Newtons

a. Devise a way to show that the forces indicated by a spring scale in Newtons are proportional to your rubber-band or saw blade units. Explain what you did and show your data and graph in the space below.

b. Find a conversion factor between your personal rubber-band units and Newtons. Explain how you determined the factor and show any calculations in the space below.

RELATING ACCELERATION AND FORCE

5.5 MEASURING ACCELERATION AS A FUNCTION OF FORCE

You have already determined that, for a situation in which friction is small, a constant force on an object causes it to accelerate at a constant rate. Now that you have a more thorough understanding of how forces can be defined and measured, you are ready to investigate the relationship between the magnitude and direction of the applied force and magnitude and direction of the resulting acceleration for different forces on a moment-by-moment basis.

Fig. 5.6. How does the measured acceleration along an *x*-axis of a low-friction cart change when the applied force on it is changed?

5.5.1. Activity: Predicting Acceleration or Velocity vs. Force

To investigate how acceleration and force are related, you will push and pull on a cart with device for measuring force. As you are pulling with a force that you can measure, you will try to cause the cart to move at a constant acceleration. You will need:

•1 small low-friction dynamics cart
•2 masses, 500 g (to add mass to the cart)
•1 force measuring
•series of markers placed on the table so that an object moving at a constant acceleration will pass one marker each second. (Refer back to the experiment with the washers on the falling string).
•1 spring scale

To do the next activity you will push and pull on a cart while measuring both the force and motion continuously. You can start laying the markers at locations that are the correct distance apart of a cart moving at a constant acceleration. Then, attach a force measurer firmly to a cart and place it on a smooth level track or surface.

5.5.2. Activity: Measuring Acceleration vs. Force

a. As you pull the cart so that it moves at a constant acceleration, watch the force measurer carefully. You may need to repeat the experiment a few times to get the constant acceleration. Repeat this process until you have reliable observations. Then describe the force measurement needed for the constant acceleration.

b. How do the force and acceleration seem to be related? Is this what you predicted in Activity 5.5.1?

Are Force and Acceleration Proportional to Each Other?

These results suggest that force and acceleration might be proportional to each other. Recall that if two variables are proportional, a graph of one variable as a function of the other is a straight line passing through the origin, and that the equation relating them would have the form

$$F_x = ma_x \qquad (5.1)$$

where F_x represents the force acting, a_x represents the acceleration, and m represents the slope of the graph and is the constant of proportionality.

5.5.3. Activity: Finding the Mathematical Relationship Between Acceleration and Force

a. Repeat the experiment for a few masses riding on the cart. For each one record the approximate value of the force needed to maintain the same constant acceleration as the first experiment. For each value record the approximate masses and forces below. .

	m (kg)	F_x(N)
1		
2		
3		
4		
5		

b. Create a graph of F_x vs. m with properly labeled axes including units and affix it on the following page. **Note:** It is conventional to plot the independent variable on the x-axis and the dependent variable on the y-axis. Using this convention, you should graph a_x as a function of F_x *because* F_x is the independent variable that you can change at will as you push or pull on the cart. However, it is more convenient in later activities if you graph F_x as a function of m for constant a instead.

(Affix your graph here.)

c. Graphs of experimentally determined relationships are seldom perfect since there is usually some scatter due to uncertainties. Taking this fact into account, does the relationship between F_x and m appear to be a proportional relationship? Why or why not?

d. If the relationship is proportional, what is the constant of proportionality (i.e., the slope of the graph)? Explain how you determined the slope and include units for it. (Fitting, mathematical modeling, drawing a best slope by hand and estimating its value, etc.)

e. Write the general equation that relates $F_{x,}$, m and a_x in terms of the symbol, m, which represents the slope of the graph.

You have just discovered a one-dimensional law of proportionality between an applied force and acceleration for the situation in which there is almost no friction. This is almost, but not quite, one of Newton's famous laws of motion. Before you can enrich the law of proportionality, you will need to explore how the properties of the object being accelerated affect the proportionality constant. In addition, you need to learn about what happens when more than one force acts on an object at the same time.

5.6 NET FORCE: ADDING AND SUBTRACTING FORCES

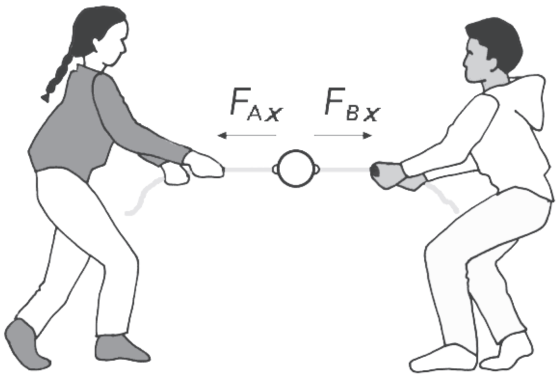


Fig. 5.9. What is the net effect of forces acting in opposite directions at the same time?

In this section we will consider what happens when more than one force acts on an object along the same line at the same time. We have not yet thought formally about how forces combine. In doing so, it is useful to treat forces as mathematical entities. Let's postulate that one-dimensional forces behave mathematically like vector components.

A one-dimensional vector component is a mathematical entity that has both a direction along an axis and a magnitude. If we choose an x-axis to lie along the same line as the one-dimensional forces we are considering, then a vector component can have a direction along the positive x-axis or a direction along the negative x-axis. The magnitude or strength of a one-dimensional force can be represented by a single number, while the direction of a force can be expressed in terms of a plus or minus sign in front of the number representing the strength of the force. One-dimensional vector components can be represented as the product of their magnitude and direction along an x-axis as shown below.

1D forces represented as vector components having the same direction

$$F_{Ax} = +5.5 \text{ N and } F_{Bx} = +3.4 \text{ N}$$

$$\text{or } F_{Ax} = -5.5 \text{ N and } F_{Bx} = -3.4 \text{ N}$$

1D forces represented as vector components acting in opposite directions

$$F_{Ax} = +2.3 \text{ N and } F_{Bx} = -7.7 \text{ N}$$

$$\text{or } F_{Ax} = -2.3 \text{ N and } F_{Bx} = +7.7 \text{ N}$$

Note: When a vector component is used to represent a physical quantity, we always include the units. In this case, the newton or N is used for force.

You can do some simple observations to determine whether or not one-dimensional forces behave like vectors. To do this you will need:

- •3 identical spring scales
- •1 small low-friction cart

5.6.1. Activity: Do 1D Forces Behave Like Vectors?

a. Describe what happens when a spring scale is hooked to one end of a resting cart and extended in a horizontal direction so that its force is equal to 2.0 N in magnitude. The force points along the positive x-axis. Does the cart move? If so, in what direction? This should be a casual observation—no need to take any data.

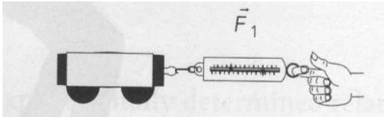


Fig. 5.10.

b. Draw an arrow that represents a scale drawing of the magnitude and direction of the force you are applying. Let one centimeter of arrow length represent each Newton of force. Label the arrow with an F_{Ax} and indicate whether F_{Ax} = +2.0 N or –2.0 N.

c. Observe what kind of motion results when two spring scales are hooked to opposite ends of the cart and extended in a horizontal direction so that each of their forces is equal to 2.0 N in magnitude but opposite in direction. Does the cart move? If so, how? What is the combined or net force on the cart? Indicate whether
F_{Bx} = +2.0 N or –2.0 N.

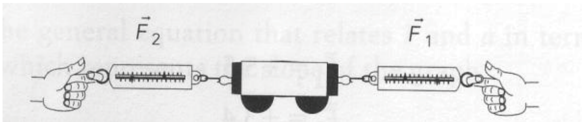


Fig. 5.11.

d. Draw arrows that represent a scale drawing of the magnitudes and directions of the forces you are applying. Let one centimeter of arrow length represent each Newton of force. Label each arrow appropriately with an F_{Ax} or an F_{Bx}.

e. What kind of motion results when two identical springs are displaced by the same amount in the same direction (e.g., when each spring is displaced to give 1.0 N of force)? How does this compare to the force of one spring displaced by twice that amount (e.g., so that it can apply 2.0 N of force)? Describe what you did and the outcome.

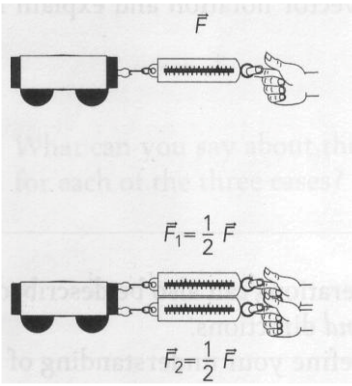


Fig. 5.12.

f. Draw arrows that represents a scale drawing of the magnitudes and directions of F_{Ax}, F_{Bx}, and F_x.

g. In the space below, fill in the number and unit that represents each vector component.

$F_x =$ ________ $F_{Ax} =$ ________ $F_{Bx} =$________

h. Do one-dimensional forces seem to behave like one-dimensional vector components? Why or why not?

If one-dimensional forces can be described as vector components, then we can denote combinations of vectors such as those in Activity 5.6.1c and e by the equation

$$F_x^{\text{net}} = \sum F_x = F_{Ax} + F_{Bx}$$

where F_x^{net} represents the sum of the vector component of two or more one-dimensional forces acting along a chosen x-axis. Some textbooks refer to a net force as a combined or total force. Other text authors write about the resultant force. Combined, total, resultant, or *net* force all refer to the same thing.

5.6.2. Activity: Calculating a Net Force

a. Let's choose an x-axis that is positive to the right and negative to the left. Suppose a force C has a magnitude of 1.5 N and acts toward the left on a cart and a second force D has a magnitude of 0.9 N and acts toward the right on a cart. Express each force in vector component notation. **Hint:** Don't forget to include the proper sign, the magnitude, and the units in each case.

b. Calculate the net force F_x^{net} using proper vector component notation and explain how you calculated it.

You should note that one-dimensional velocities and accelerations can also be described by vector components because they too have magnitudes *and* directions.

One of your goals is to continue to refine your understanding of the relationship between one-dimensional forces and motion. You just investigated how one-dimensional forces combine like vector components in terms of their ability to cause acceleration. *We can now state that acceleration caused by several forces acting in one dimension on an object that experiences very little friction is proportional to the net force on the object.*

5.7 WHAT HAPPENS WHEN THE NET FORCE IS ZERO?

Let's consider an important special situation in more detail—the situation in which the net force acting in one dimension on an object in the absence of significant friction is zero. Start by summarizing what you already know.

5.7.1. Activity: Facts About Zero Net Force and Motion

a. Suppose we apply a force in the positive direction along an x-axis (toward the right) on a small low-friction cart and another force acting along the same line of equal magnitude in the negative direction on the cart (toward the left). If the law of proportionality between force and acceleration holds, what will the acceleration vector component, a_x, of the cart be? **Hint:** Don't forget to include units!

$a_x =$ ____________________

b. What is the acceleration component of a cart that is:

1. at rest?

$a_x =$ ____________________

2. moving with a constant negative velocity along an x-axis?

$a_x =$ ____________________

3. moving with a constant positive velocity along an x-axis?

$a_x =$ ____________________

c. Suppose an object is moving with a constant velocity and experiences no net applied forces and no friction. Is its continued motion with a constant velocity compatible with the law of proportionality between net force and acceleration or does it violate that law?

d. What can you say about the net force component on the cart mentioned in part b for each of the three cases?

We would like you to investigate whether or not a low-friction cart that has a zero net force on it can move at a constant velocity. To undertake this investigation we suggest that you apply forces in opposite directions with the same strength on a cart using two spring scales.

5.7.2. Activity: Motion with No Net Force

a. Suppose a cart receives a brief push that starts it moving in one direction or another. If there is no net force on it after the push, what do you predict its motion will be like? Try to imagine that there is no friction acting on the cart. Explain the reasons for your prediction.

b. Is your prediction compatible with the proportional relationship between force and acceleration that you discovered previously?

c. Observe what happens after the cart is pushed in one direction and allowed to move freely with no net force. Describe your observation. Is the velocity of the cart constant or decreasing? Does the cart seem to be accelerating?

d. The observation you just made should enable you to state Newton's First Law of Motion. *Please finish the statement in a way that is compatible with your actual observation*.

NEWTON'S FIRST LAW: If an object moving at a constant velocity, v, without friction experiences no net force, it will . . .

Remarks About Newton's First Law

Newton's First Law is of deep significance because it allows an observer who is moving at a constant velocity with respect to another observer to discover the same laws of motion. For example, suppose you observe that the small cart is at rest in the laboratory and your partner makes the same observation while moving away from you at a constant velocity on a bicycle. Your partner will see the small cart moving away with a constant velocity. But both of you can agree that the cart is not accelerating and therefore is experiencing no net force!

RELATING FORCE, MASS, AND ACCELERATION

5.8 DEFINING AND MEASURING MASS

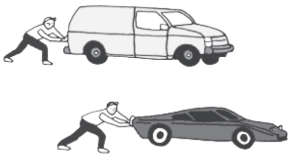


Fig. 5.14. Would you rather push a sports car or a larger van?

A good friend calls you in a panic. His battery is dead and he needs to have you come outside and help push his car to get it started. He needs to have you get it moving at about 18 KPH so he can throw it in gear and turn over the engine. You blithely answer sure, you'll be right out. Then you remember that your friend owns two vehicles—a large delivery van and a smaller sports car. Since you can exert only so much force and you're feeling like a 40 kg weakling, you hope that your friend is driving the easier of the two cars to push.

5.8.1. Activity: Causing a Car to Accelerate

a. Which vehicle do you think would be easier to accelerate from rest to a speed of 18 KPH with a given force—a small car or a large van? Explain.

b. What characteristic of an object seems to determine how much force is needed to accelerate it?

Somehow the magnitude of force required to cause an object to accelerate by a given amount is related to the "amount of stuff" being accelerated. It is pretty obvious to most people that if there is more stuff, then more force will be required to accelerate it. But suppose we double the amount of stuff. Will that mean that twice the force is needed to accelerate double the stuff?

The stuff we are referring to is what scientists usually call mass. Let's take some time to consider the question of what mass is and how we might measure it.

What Is Mass?

Philosophers of science are known to have great debates about the definition of mass. If we assume that mass refers somehow to "amount of stuff," then we can develop an operational definition of mass for matter that is made up of particles that appear to be identical. We can assume that mass adds up and that two identical particles when combined have twice the mass of one particle; three particles have three times the mass; and so on. But suppose we have two objects that have different shapes and are made of different stuff, such as a small lead pellet and a silver coin. How can we tell if these two entities have the same mass?

5.8.2. Activity: Ideas About Mass and Its Measurement

a. Attempt to define *mass* in your own words without using the word "stuff."

b. How many different ways can you think of to determine whether a lead pellet and a silver coin have the same mass?

c. Suppose you find that the lead pellet and the silver coin seem to have the same mass. How could you create "stuff" that has twice the mass of either of the original objects?

Using a Mass Balance

One time-honored way that people have used to compare the mass of two objects is to put them on a balance. If they happen to balance each other, we say that the "force of gravity" or the force of attraction exerted on them by the earth is the same, so they must have the same mass.

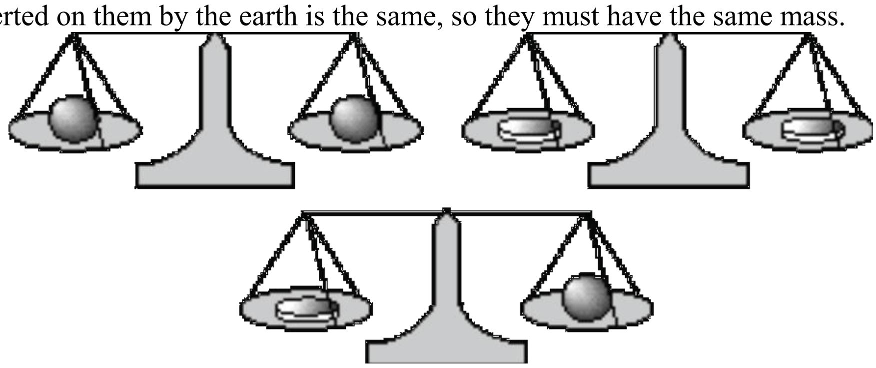


Fig. 5.15. A common method of determining mass that assumes two objects have the same mass if they experience the same gravitational force.

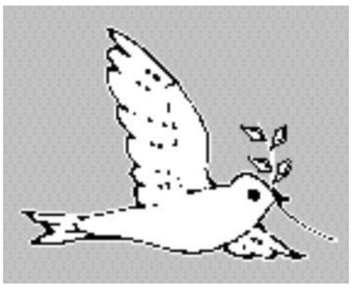


Fig. 5.16.

Actually, if we balance gravitational forces as the method of determining mass, we are only determining a *passive gravitational mass*. A passive gravitational mass is proportional to the force of attraction exerted by the earth on the mass. How can we use a balance to measure the mass of any object relative to a standard mass?

Let's do a thought experiment. Suppose Maya makes the outrageous claim that her dove has the same mass as 79 silver quarters and is worth her weight in quarters. Can you double check her claim using a balance, a quarter as the "standard mass," and a pile of sand? **Hint:** This is an exercise in basic logic.

5.8.3. Activity: Using a Balance to Measure an Arbitrary Mass

Explain how you might measure the passive gravitational mass of Maya's dove using the balance, sand, and standard coin.

Other Ways to Measure Passive Gravitational Mass

In most modern laboratories, spring scales and electronic scales that are easier to use now replace the old-fashioned balance. As the earth attracts a mass hanging from a spring, the spring will stretch. A mass placed on the platform of an electronic scale will cause it to depress. The amount of depression can be detected electronically.

5.9 HOW MASS AFFECTS MOTION

You have already verified a law of proportionality between one-dimensional force and acceleration when little friction is present. This law can be expressed in the form

$$F_x^{\text{net}} = ma_x \qquad (5.1)$$

where F_x^{net} is the net force exerted on an object, m is the slope of the graph of F_x^{net} vs. a_x or the constant of proportionality, and a_x is the acceleration along the line that the net force acts. We know that this constant of proportionality, m, which represents a resistance of an object to acceleration, doesn't necessarily have anything to do with gravity.

Since it requires more force to accelerate more gravitational mass our intuition tells us that the proportionality constant ought to be related to passive gravitational mass. Is it possible that the passive gravitational mass of an object is the same as the proportionality constant, or slope, relating F_x and a_x? In other words, *will accelerating twice as much passive gravitational mass by the same amount take twice as much force*? This is the question we posed in Section 5.7.

To answer this question you should investigate the forces and accelerations that arise when you push and pull on rolling carts having different passive gravitational masses. This investigation is basically an extension of the one you undertook in Section 5.5. For the next activity you will need:

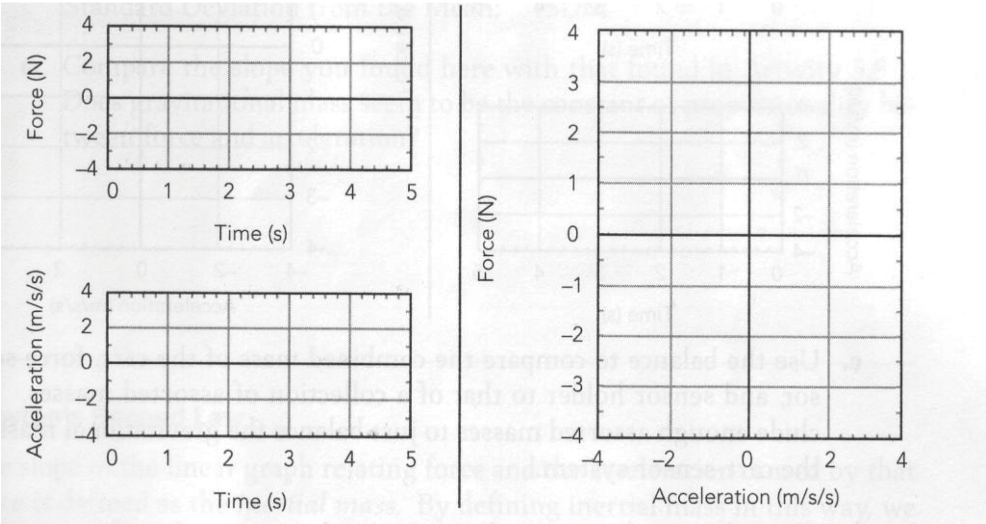
- 1force measurer
- 1 small low-friction dynamics cart
- 1 set of assorted masses (1 g, 2 g, 5 g, 10 g, 20 g, 50 g, 100 g, 200 g)

Before doing the activity, attach a force measurer firmly to the cart. Place the cart on a smooth level surface.

If needed, calibrate the force sensor to read forces between -5 and +5 N.

5.9.1. Activity: Measuring Acceleration vs. Force

a. Observe the acceleration and sketch qualitatively the force and acceleration graphs you observed.



Doubling the Gravitational Mass

Suppose you put enough mass on the cart to double its mass. How much more force must you exert to push and pull on the more massive cart so that its acceleration vs. time graph looks about the same as the graph you sketched in Activity 5.9.1a?

5.9.2. Activity: Acceleration vs. Force for Twice the Mass

a. Suppose you were able to push and pull on a cart having twice the mass as before so that the acceleration vs. time is approximately the same. Do you think the slope of the *F* vs. *a* graph will increase, decrease, or remain the same? Explain.

b. Sketch the predicted shapes of all three graphs.

c. Compare the approximate slopes you found here with that found in Activity 5.9.1. Does gravitational mass seem to be the constant of proportionality between force and acceleration?

Newton's Second Law

The slope of the linear graph relating the one-dimensional force and the acceleration caused by that force is defined as the *inertial mass*. By defining inertial mass in this way, we have developed sensible definitions of force and mass that lead to Newton's Second Law of Motion for one-dimensional motions in the absence of friction. Newton's Second Law expressed in vector component notation for an object having a total inertial mass of m is simply

$$F_x^{net} = \sum F_x = ma_x \qquad (5.2)$$

where ΣF_x is a vector component representing the net one-dimensional force on the object, and a_x is a vector component representing the acceleration caused by the net force.

Inertial and Passive Gravitational Mass

In the last activity you have shown that within the limits of experimental uncertainty inertial and passive gravitational masses are the same. This makes the definition of inertial mass as the proportionality constant between acceleration and force seem less arbitrary.
It is not obvious that these two definitions of mass—passive gravitational and inertial—should yield exactly the same results. This equivalence is assumed in both Newton's theory of gravity and Einstein's general relativistic modifications of it. In fact, sophisticated experiments have shown that within the limits of experimental uncertainty, there is no difference between the two types of mass to within one part in 10^{11}.

Standard SI Units for Mass and Force

As you already know, the Systemè Internationale, or SI system of units provides us with a standard set of units that we often use. This system was established in 1960 to provide units that all scientists throughout the world should use. The SI units for fundamental quantities used in mechanics, including mass, are shown below.

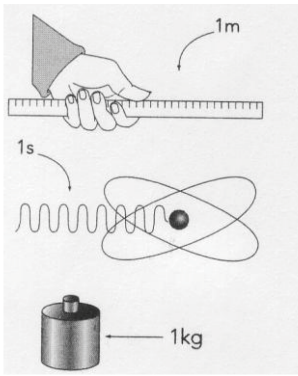


Fig. 5.18.

SI UNITS FOR MECHANICS

Length: A **meter** (m) is the distance traveled by light in a vacuum during a time of 1/299,792,458 second.

Time: A **second** (s) is defined as the time required for a light wave given off by a cesium–133 atom to undergo 9,192,631,770 vibrations.

Mass: A **kilogram** (kg) is defined as the mass of a platinum–iridium alloy cylinder kept in a special chamber at the International Bureau of Weights and Measures in Sévres, France.

The electronic balance and spring scales often used in laboratories have been calibrated using replicas of the "real" standard kilogram mass kept in a vault in France. These fundamental units and Newton's Second Law can also be used to define the Newton as a unit of force. The Newton is defined in terms of mass and acceleration as shown in the box below.

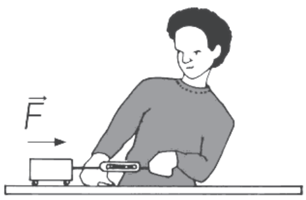


Fig. 5.19.
1 N = 1 kg • m/s/s

The SI Force Unit Expressed in Terms of Length, Mass and Time Force: A **Newton** (N) is defined as that force, which, when acting on a 1-kg mass, causes an acceleration of 1 m/s/s.

Do the Standard Units Work Together?

With the exception of a device called an inertial balance, essentially all the common equipment used in laboratories today measures passive gravitational mass rather than inertial mass. Thus, if you determine the mass in kilograms of your cart and force sensor system using an electronic balance, you can compare it to the inertial mass you found by accelerating your cart system in Activity 5.9.1.

Since you measured forces in Newtons and accelerations in m/s/s, the passive gravitational mass readings from a well-calibrated electronic balance and the inertial mass readings from the slopes of your F vs. a lines should be the same. Are they?

5.10 SUMMARIZING NEWTON'S FIRST AND SECOND LAWS

The main purpose of Unit 5 has been to explore the relationships between forces on an object, its mass, and its acceleration. You have been trying to develop Newton's first two laws of motion for one-dimensional situations in which all forces lie in a positive or negative direction along the same line and in which there is very little friction present.

5.10.1. Activity: Newton's Laws in Your Own Words

Express Newton's Laws in your own words clearly and precisely.

- The First Law (the one about constant velocity):

- The Second Law (the one relating force, mass, and acceleration):

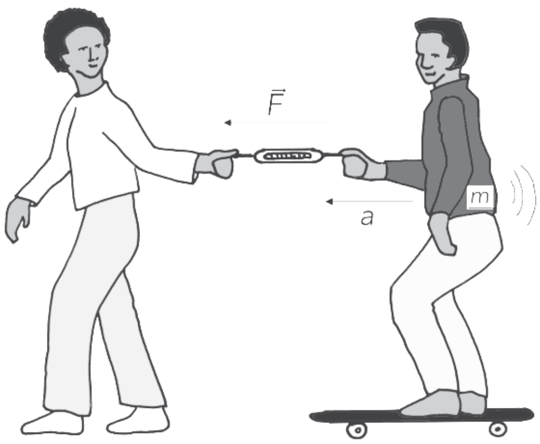


Fig. 5.20.

5.10.2. Activity: Newton's Laws in Equation Form

Express Newton's Laws in equations in terms of the acceleration or velocity vector, the net force on an object, and its mass:

The First Law: If $F_x^{net} = \sum F_x = 0$ then $v_x =$ or

Note: The use of the equal sign does not signify that an acceleration is the same as or equivalent to a force divided by a mass, but instead it spells out a procedure for calculating the magnitude and direction of the acceleration of a mass while it is experiencing a net force. What we assume when we believe in Newton's Second Law is that a net force on a mass causes an acceleration of that mass.

The Second Law: If $F_x^{net} \neq 0$ then $a_x =$

Fig. 5.21. Newton recognized that the laws of motion discovered through the use of applied forces could also be used to discover the nature of gravitational forces and the forces of friction.

Final Comments on Force, Mass, and Motion

You started your study of Newtonian dynamics in this unit by attempting to develop the concept of force. Initially, when asked to define force, most people think of a *force* as an *obvious push or pull* such as a punch to the jaw or the tug of a rubber band. By studying the acceleration that results from a force when little friction is present, we can come up with a second definition of *force* as *that which causes acceleration*. These two alternative definitions of force do not seem to be the same at all. Pulling on a hook attached to a wall doesn't seem to cause the wall to move. An object dropped close to the surface of the earth accelerates and yet there is no visible push or pull on it.

The genius of Newton was to recognize that he could define *net force* as that which causes acceleration. He reasoned that if the applied forces did not account for the degree of acceleration then other "invisible" forces must be present. A prime example of an invisible force is that of gravity—the attraction of the earth for objects.

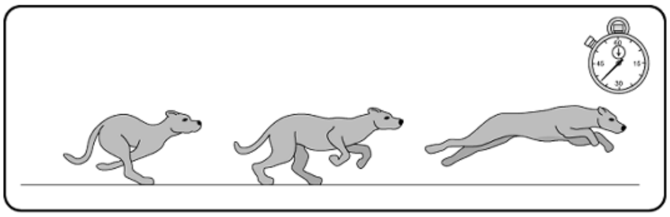
Finding invisible forces is hard sometimes because some of them are known as *passive* forces because they only seem to act in response to either the motion of an object or other forces on it. Friction forces are one example of passive forces. They are not only invisible, but they only crop up during motions for the purpose of inhibiting the motion. The passive nature of friction is obvious when you think of a person riding on a garbage bag and sliding along the floor at constant velocity under the influence of an applied force.

According the Newton's First Law, a person moving at a constant velocity must have no net force on her. Newton thought that the applied force in one direction had to be opposed by a friction force acting in the other direction to oppose her motion. The friction force must be passive because, if the applied force is discontinued, the friction force does cause the sliding person to slow down until she has no motion. Then the friction force stops acting. If it didn't stop acting, the person would slow down and then turn around and speed up in the opposite direction. This doesn't happen!

During the rest of our study of the Newtonian formulation of classical mechanics your task will be to discover and invent new types of active and passive forces so that you can continue to explain and predict motions using Newton's Laws. In the next unit you will be using Newton's Laws to explain why sliding masses that have no visible forces on them slow down and come to rest, and to learn why masses fall when dropped close to the surface of the Earth. You will also learn how to extend Newton's Laws to two-dimensional situations when the motion of an object and the forces that act on it *do not lie along the same line*

Name__________________________________Date______________________Partners________________________________

LAB 2: CHANGING MOTION



A cheetah can accelerate from 0 to 50 miles per hour in 6.4 seconds.
–Encyclopedia of the Animal World

A Jaguar can accelerate from 0 to 50 miles per hour in 6.1 seconds.
–World Cars

OBJECTIVES

- To discover how and when objects accelerate.
- To understand the meaning of acceleration, its magnitude, and its direction.
- To discover the relationship between velocity and acceleration graphs.
- To learn how to represent velocity and acceleration using vectors.
- To learn how to find average acceleration from acceleration graphs.
- To learn how to calculate average acceleration from velocity graphs.

OVERVIEW

In the previous lab, you looked at position—time and velocity—time graphs of the motion of your body and a cart at a constant velocity. You also looked at the acceleration—time graph of the cart. The data for the graphs were collected using a motion detector. Your goal in this lab is to learn how to describe various kinds of motion in more detail.

You have probably realized that a velocity—time graph is easier to use than a position—time graph when you want to know how fast and in what direction you are moving at each instant in time as you walk (even though you can calculate this information from a position—time graph).

It is not enough when studying motion in physics to simply say that “the object is moving toward the right” or “it is standing still.” When the velocity of an object is changing, it is also important to describe how it is changing. The rate of change of velocity with respect to time is known as the *acceleration*.

To get a feeling for acceleration, it is helpful to create and learn to interpret velocity—time and acceleration—time graphs for some relatively simple motions of a cart on a smooth ramp or other level surface. You will be observing the cart with the motion detector as it moves with its velocity changing at a constant rate.

INVESTIGATION 1: VELOCITY AND ACCELERATION GRAPHS

In this investigation you will be asked to predict and observe the shapes of velocity—time and acceleration—time graphs of a cart moving along a smooth ramp or other level surface. You will focus on cart motions with a steadily increasing velocity.

You will need the following materials:

- computer-based laboratory system
- motion detector
- motion software
- *RealTime Physics Mechanics* experiment configuration files
- cart with very little friction
- smooth ramp or other level surface 2—3 m long
- fan unit attachment with batteries and dummy cells (or with a speed adjustment control)

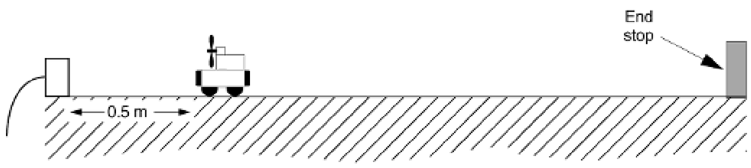
Activity 1-1: Speeding Up

In this activity you will look at velocity—time and acceleration—time graphs of the motion of a cart, and you will be able to see how these two representations of the motion are related to each other when the cart is speeding up.

This could be done by moving the cart with your hand, but it is difficult to get a smoothly changing velocity in this way. Instead you will use a fan or propeller driven by an electric motor to accelerate the cart.

1. Set up the cart on the ramp, with the fan unit and motion detector as shown below. Tape the fan unit securely to the cart. *Be sure that the ramp is level. Be sure that the fan blade does not extend beyond the end of the cart facing the motion detector. (If it does, the motion detector may collect bad data from the rotating blade.)*

2. If the cart has a friction pad, move it out of contact with the ramp so that the cart can move freely.



3. Open the experiment file called **Speeding Up (L2A1-1)** to display the axes that follow.

4. Use a position graph to make sure that the detector can "see" the cart all the way to the end of the ramp. You may need to tilt the detector up slightly.

5. Make sure the switch is off, then place half batteries and half dummy cells in the battery compartment of the fan unit (or use all batteries, and set the dial at about half maximum speed of the fan blade). *To preserve the batteries, switch on the fan unit only when you are making measurements.*

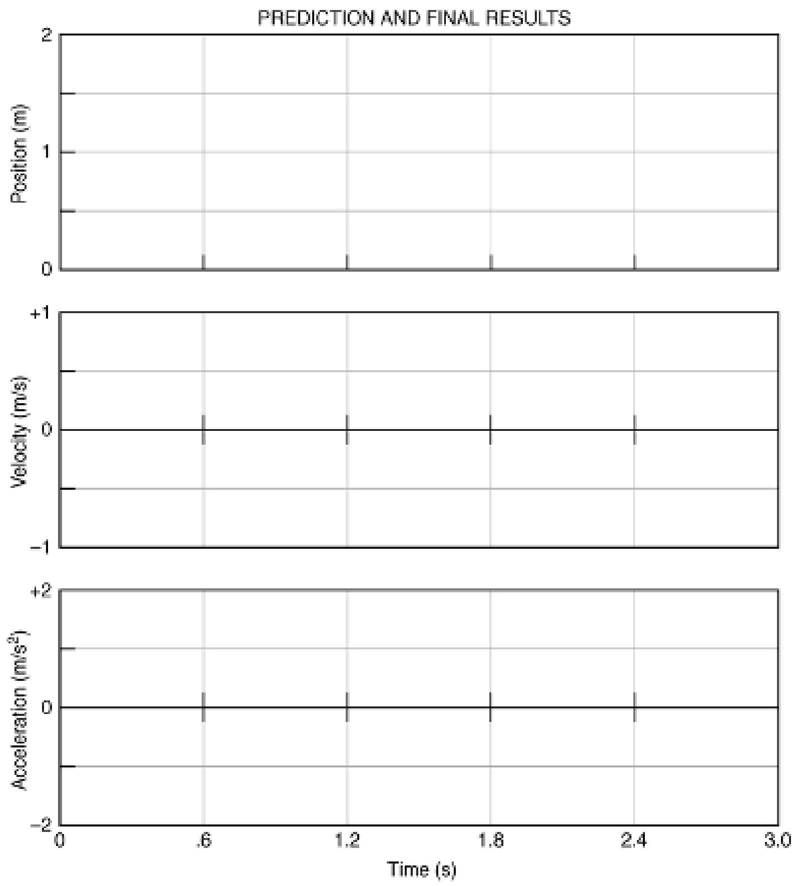
6. **Graph velocity first**. Hold the cart with your hand on its side, **begin graphing**, switch the fan unit on and when you hear the clicks of the motion detector, release the cart from rest. *Do not put your hand between the cart and the detector. Be sure to stop the cart before it hits the end stop. Turn off the fan unit.*

   Repeat, if necessary, until you get a nice set of graphs.

   Adjust the position and velocity axes if necessary so that the graphs fill the axes. Use the features of your software to transfer your data so that the graphs will remain **persistently displayed on the screen**.

   Also **save your data** for analysis in Investigation 2. (Name your file **SPEEDUP1.XXX**, where **XXX** are your initials.)

7. Sketch your position and velocity graphs neatly on the axes that follow. Label the graphs "*Speeding Up 1*." (Ignore the acceleration axes for now.)



Question 1-1: How does your position graph differ from the position graphs for steady (constant velocity) motion that you observed in Lab 1: Introduction to Motion?

Question 1-2: What feature of your velocity graph signifies that the motion was away from the motion detector?

Question 1-3: What feature of your velocity graph signifies that the cart was *speeding up*? How would a graph of motion with a constant velocity differ?

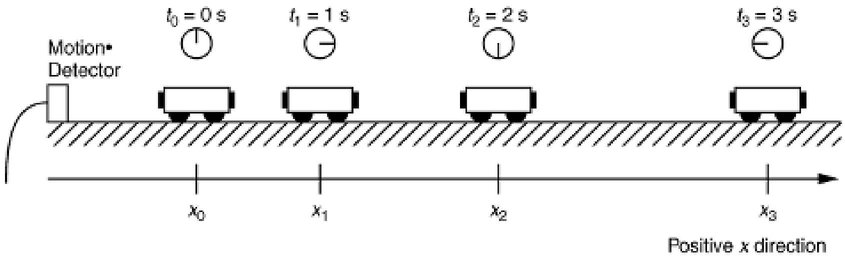
8. Adjust the acceleration scale so that your graph fills the axes. Sketch your graph on the acceleration axes above, and label it "*Speeding Up 1*."

Question 1-4: During the time that the cart is speeding up, is the acceleration positive or negative? How does *speeding up* while moving *away* from the detector result in this sign of acceleration? (**Hint**: Remember that acceleration is the *rate of change* of velocity. Look at how the velocity is changing. It takes two points on the velocity—time graph to calculate the rate of change of velocity.)

Question 1-5: How does the velocity vary in time as the cart speeds up? Does it increase at a steady (constant) rate or in some other way?

Question 1-6: How does the acceleration vary in time as the cart speeds up? Is this what you expect based on the velocity graph? Explain.

Question 1-7: The diagram below shows the positions of a cart at equal time intervals as it speeds up.



At each indicated time, sketch a vector above the cart that might represent the velocity of the cart at that time while it is moving away from the motion detector and speeding up.

Question 1-8: Show below how you would find the vector representing the change in velocity between the times 1 and 2 s in the diagram above. **(Hint**: Remember that the change in velocity is the final velocity minus the initial velocity, and the vector difference is the same as the sum of one vector and the negative of the other vector.)

Based on the direction of this vector and the direction of the positive *x* axis, what is the sign of the acceleration? Does this agree with your answer to Question 1-4?

Activity 1-2: Speeding Up More

Prediction 1-1: Suppose that you accelerate the cart at a faster rate. How would your velocity and acceleration graphs be different? Sketch your predictions with dashed or different color lines on the previous set of axes.

1. Test your predictions. Make velocity and acceleration graphs. This time accelerate the cart with the maximum number of batteries in the battery compartment (or set the dial to the maximum speed of the fan blade). *Remember to switch the fan unit on only when making measurements.*

Repeat if necessary to get nice graphs. (Leave the original graphs **persistently displayed on the screen**.) When you get a nice set of graphs, **save your data** as **SPEEDUP2.XXX** for analysis in Investigation 2.

2. Sketch your velocity and acceleration graphs with solid or different color lines on the previous set of axes, or **print** the graphs and affix them over the axes. Be sure that the graphs are labeled "*Speeding Up 1*" and "*Speeding Up 2*."

Question 1-9: Did the shapes of your velocity and acceleration graphs agree with your predictions? How is the magnitude (size) of acceleration represented on a velocity—time graph?

Question 1-10: How is the magnitude (size) of acceleration represented on an acceleration—time graph?

INVESTIGATION 2: MEASURING ACCELERATION

In this investigation you will examine the motion of a cart accelerated along a level surface by a battery driven fan more quantitatively. This analysis will be quantitative in the sense that your results will consist of numbers. You will determine the cart's acceleration from your velocity—time graph and compare it to the acceleration read from the acceleration—time graph.

You will need motion software and the data files you saved from Investigation 1.

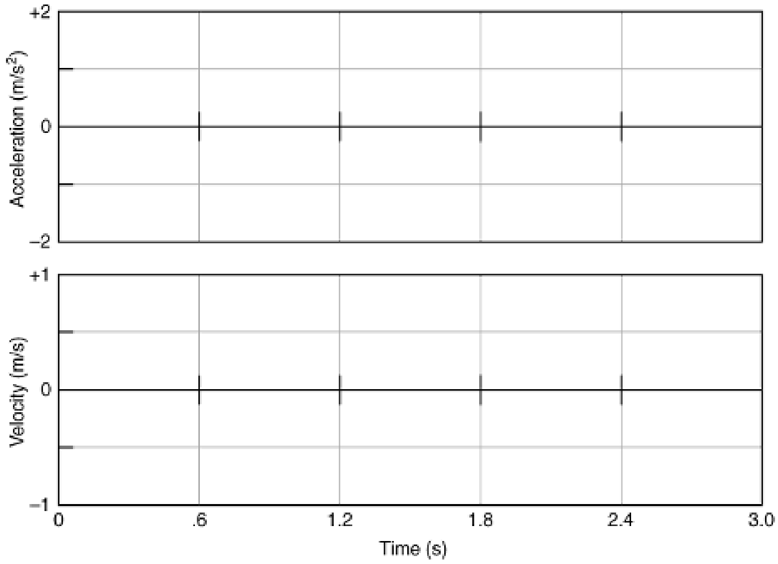
Activity 2-1: Velocity and Acceleration of a Cart That Is Speeding Up

1. The data for the cart accelerated along the ramp with half batteries and half dummy cells (Investigation 1, Activity 1-1) should still be

persistently on the screen. (If not, **load the data** from the file **SPEEDUP1.XXX.**)

Display velocity and acceleration, and **adjust the axes** if necessary.

2. Sketch the velocity and acceleration graphs again below, or **print,** and affix a copy of the graphs. Correct the scales if necessary.



3. Find the average acceleration of the cart from your acceleration graph. Use the **analysis feature** in the software to read a number of values (say 10) of the acceleration, which are equally spaced in time. (Only use values from the portion of the graph after the cart was released and before the cart was stopped.)

Acceleration values (m/s^2)			
1		6	
2		7	
3		8	
4		9	
5		10	

Average (mean) acceleration: ______m/s^2

Comment: Average acceleration during a particular time interval is defined as thea average rate of change of velocity with respect—the change in velocity divided by the change in time. By definition, the rate of change of a quantity graphed with repsect to time is also the *slope* of the curve. Thus, the (average) slope of an object's velocity-time graph is also the (average) acceleration of the object.

4. Calculate the slope of your velocity graph. Use the **analysis feature** of your software to read the velocity and time coordinates for two typical points on the velocity graph. (For a more accurate answer, use two points as far apart in time as possible but still during the time the cart was speeding up.)

	Velocity (m/s)	Time (s)
Point 1		
Point 2		

Calculate the change in velocity between points 1 and 2. Also calculate the corresponding change in time (time interval). Divide the change in velocity by the change in time. This is the *average* acceleration. Show your calculations below.

Speeding up	
Change in velocity (m/s)	
Time interval (s)	
Average acceleration (m/s^2)	

Question 2-1: Is the acceleration positive or negative? Is this what you expected?

Question 2-2: Does the average acceleration you just calculated agree with the average acceleration you found from the acceleration graph? Do you expect them to agree? How would you account for any differences?

Activity 2-2: Speeding Up More

1. **Load the data** from your file **SPEEDUP2.XXX** (Investigation 1, Activity 1-2). **Display velocity and acceleration**.

2. Sketch the velocity and acceleration graphs or **print** and affix the graphs. Use dashed lines on the previous set of axes.

3. Use the **analysis feature** of the software to read acceleration values, and find the average acceleration of the cart from your acceleration graph.

Acceleration values (m/s^2)			
1		6	
2		7	
3		8	
4		9	
5		10	

Average (mean) acceleration: ______m/s^2

4. Calculate the average acceleration from your velocity graph. Remember to use two points as far apart in time as possible, but still having typical values.

	Velocity (m/s)	Time (s)
Point 1		
Point 2		

Calculate the *average* acceleration.

Speeding up	
Change in velocity (m/s)	
Time interval (s)	
Average acceleration (m/s^2)	

Question 2-3: Does the average acceleration calculated from velocities and times agree with the average acceleration you found from the acceleration graph? How would you account for any differences?

Question 2-4: Compare this average acceleration to that with half batteries and half dummy cells (Activity 2-1). Which is larger? Is this what you expected?

If you have additional time, do the following Extension.

Extension 2-3: Using Statistics and Fit to Find the Average Acceleration

In Activity 2-1 and 2-2, you found the value of the average acceleration for a motion with steadily increasing velocity in two ways: from the average of a number of values on an acceleration—time graph and from the slope of the velocity—time graph. The **statistics feature** in the software allows you to find the average (mean) value directly from the acceleration—time graph. The **fit routine** allows you to find the line that best fits your velocity—time graph from Activity 2-1 and 2-2. The equation of this line includes a value for the slope.

1. *Using **Statistics***: **Load** your **SPEEDUP1.XXX** file. You must first **select the portion** of the acceleration—time graph for which you want to find the mean value.

Next, use the **statistics feature** and read the mean value of acceleration from the table: ______m/s^2

Question E2-5: Compare this value to the one you found from 10 measurements in Activity 2-1.

2. *Using **Fit***: You must first **select the portion** of the velocity—time graph that you want to fit.

Next, use the **fit routine** to try a linear fit, $v = b + ct$.

Record the equation of the fit line, and compare the value of the slope (*c*) to the velocity you found in Activity 2-1.

Question E2-6: What is the meaning of *b*?

Question E2-7: How do the two values of acceleration that you found here agree with each other? Is this what you expected?

Find the average acceleration for the motion in your **SPEEDUP2.XXX** file from the acceleration—time and velocity—time graphs using the same methods. Compare the values to those found in Activity 2-2.

INVESTIGATION 3: SLOWING DOWN AND SPEEDING UP

In this investigation you will look at a cart moving along a ramp or other level surface *and slowing down*. A car being driven down a road and brought to rest when the brakes are applied is a good example of this type of motion.

Later you will examine the motion of the cart *toward* the motion detector and *speeding up*.

In both cases, we are interested in how velocity and acceleration change over time. That is, we are interested in the shapes of the velocity—time and acceleration—time graphs (and their relationship to each other), as well as the vectors representing velocity and acceleration.

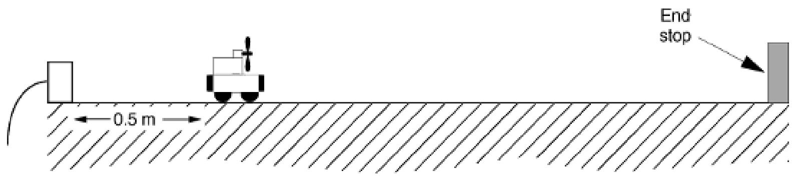
You will need the following materials:

- computer-based laboratory system
- motion detector
- motion software
- *RealTime Physics Mechanics* experiment configuration files
- cart with very little friction
- smooth ramp or other level surface 2—3 m long
- fan unit attachment with batteries

Activity 3-1: Slowing Down

In this activity you will look at the velocity and acceleration graphs of the cart moving *away from* the motion detector and *slowing down*.

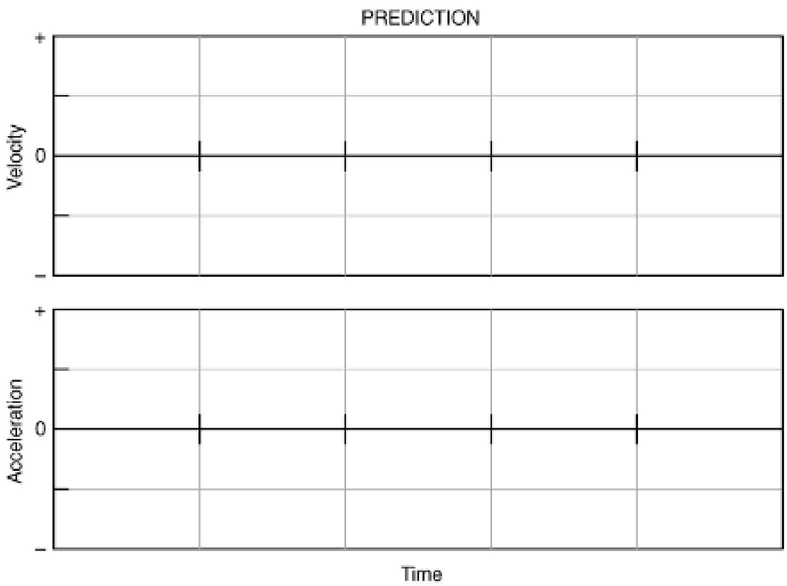
1. The cart, ramp, and motion detector should be set up as in Investigation 1. Use the maximum number of batteries (or set the dial to the maximum speed). The fan should be pushing the cart *toward* the motion detector.



Now, when you give the cart a quick push away from the motion detector with the fan running, it will slow down after it is released.

Prediction 3-1: If you give the cart a short push away from the motion detector and release it, will the acceleration be positive, negative, or zero (after it is released)?

Sketch your predictions for the velocity—time and acceleration—time graphs on the axes below.

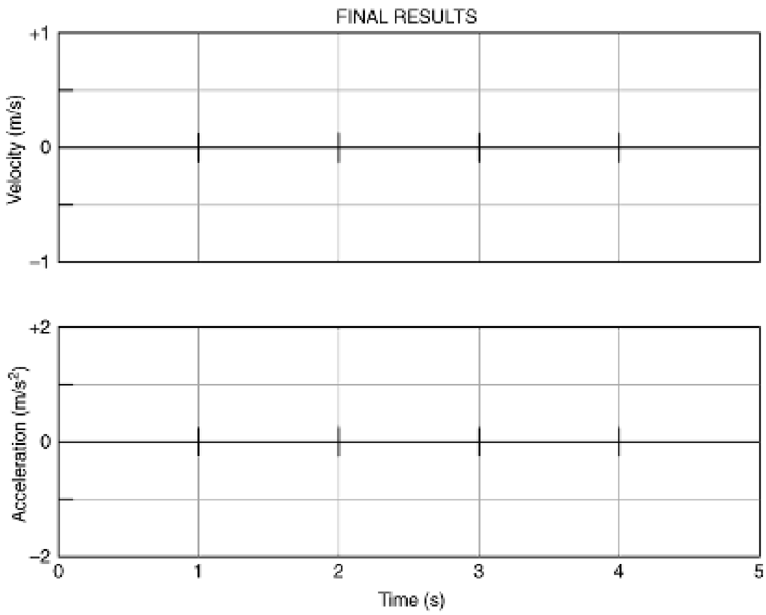


2. Test your predictions. Open the experiment file called **Slowing Down (L2A3-1)** to display the velocity—time and acceleration—time axes that follow.

3. **Graph velocity first. Begin graphing** with the back of the cart near the 0.5-m mark. Turn the fan unit on, and when you begin to hear the clicks from the motion detector, give the cart a gentle push away from the detector so that it comes to a stop near the end of the ramp. (*Be sure that your hand is not between the cart and the detector*.) *Stop the cart–do not let it return toward the motion detector–and turn the fan unit off immediately to save the batteries*.

You may have to try a few times to get a good run. Don't forget to **change the axes** if this will make your graphs easier to read.

Move your data so that the graphs are **persistently displayed on the screen**.



4. Neatly sketch your results on the previous axes, or **print** the graphs and affix them over the axes.

Label your graphs with

- A at the spot where you started pushing.
- B at the spot where you stopped pushing.
- C the region where only the force of the fan is acting on the cart
- D at the spot where the cart stopped moving.

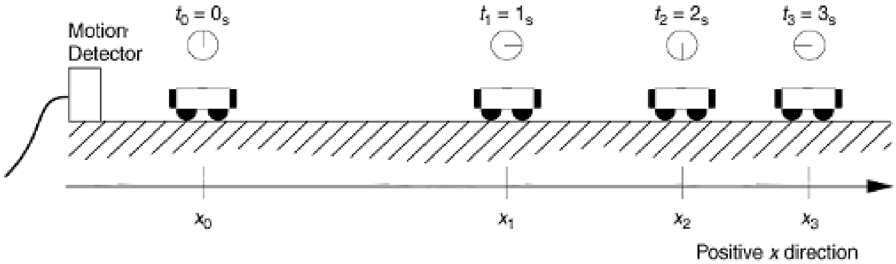
Also sketch on the same axes the velocity and acceleration graphs for *Speeding Up 2* from Activity 1-2.

Question 3-1: Did the shapes of your velocity and acceleration graphs agree with your predictions? How can you tell the sign of the acceleration from a velocity—time graph?

Question 3-2: How can you tell the sign of the acceleration from an acceleration—time graph?

Question 3-3: Is the sign of the acceleration (which indicates its direction) what you predicted? How does *slowing down* while moving *away* from the detector result in this sign of acceleration? (**Hint**: Remember that acceleration is the *rate of change* of velocity with respect to time. Look at how the velocity is changing.)

Question 3-4: The diagram below shows the positions of the cart at equal time intervals. (This is like overlaying snapshots of the cart at equal time intervals.) At each indicated time, sketch a vector above the cart that might represent the velocity of the cart at that time while it is moving away from the motion detector and slowing down.



Question 3-5: Show below how you would find the vector representing the change in velocity between the times 1 and 2 s in the diagram above. (Remember that the change in velocity is the final velocity minus the initial velocity.)

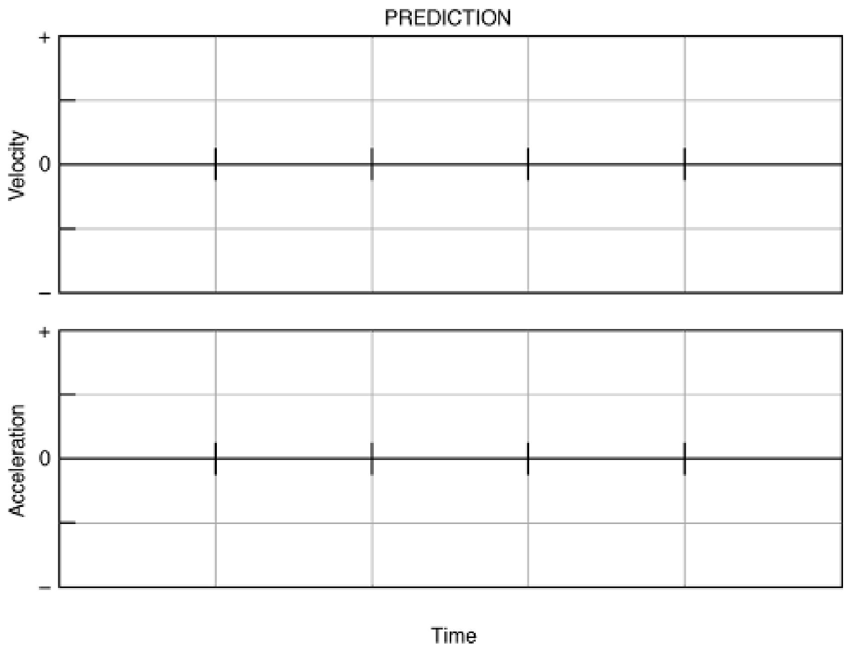
Based on the direction of this vector and the direction of the positive *x* axis, what is the sign (the direction) of the acceleration? Does this agree with your answer to Question 3-3?

Question 3-6: Based on your observations in this lab, state a general rule to predict the sign (the direction) of the acceleration if you know the sign of the velocity (i.e., the direction of motion) and whether the object is speeding up or slowing down.

Activity 3-2 Speeding Up Toward the Motion Detector

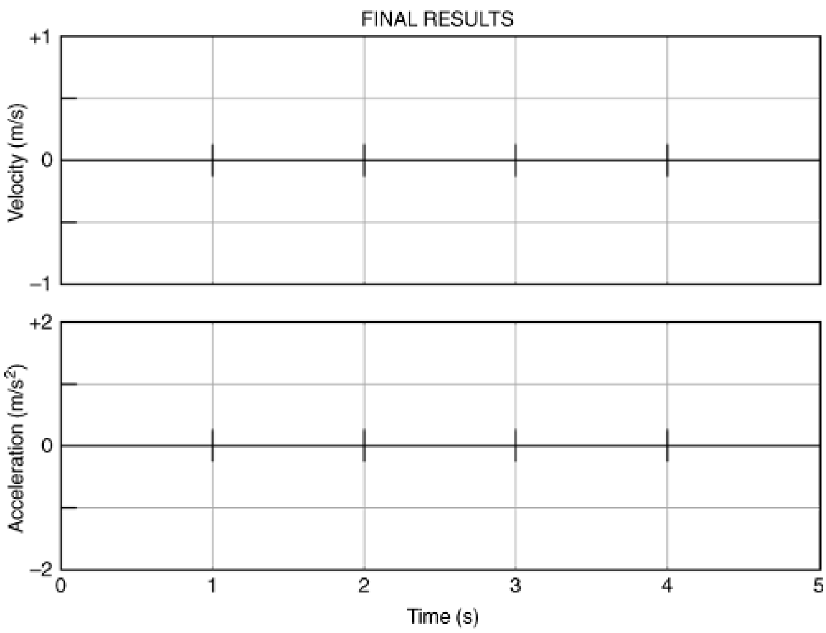
Prediction 3-2: Suppose now that you start with the cart at the far end of the ramp, and let the fan push it *toward* the motion detector. As the cart moves toward the detector and speeds up, predict the direction of the acceleration. Will the sign (direction) of the acceleration be positive or negative? (Use your general rule from Question 3-6.)

Sketch your predictions for the velocity—time and acceleration—time graphs on the axes that follow.



1. Test your predictions. First **clear** any previous graphs. **Graph velocity first**. Graph the cart moving *toward* the detector and *speeding up*. Turn the fan unit on, and when you hear the clicks from the motion detector, release the cart from rest from the far end of the ramp. (*Be sure that your hand is not between the cart and the detector.) Stop the cart when it reaches the 0.5-m line, and turn the fan unit off immediately.*

2. Sketch these graphs or **print** and affix on the axes below. Label these graphs as "*Speeding Up Moving Toward*."

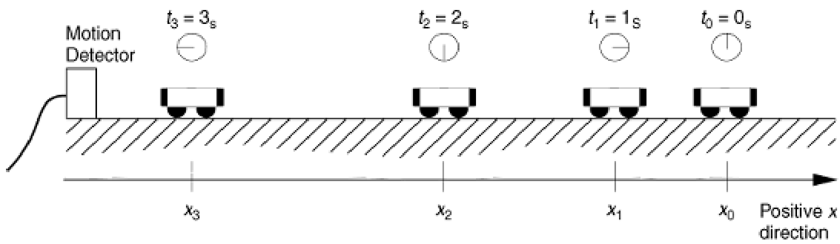


Question 3-7: How does your velocity graph show that the cart was moving *toward* the detector?

Question 3-8: During the time that the cart was speeding up, is the acceleration positive or negative? Does this agree with your prediction? Explain how *speeding up* while moving *toward* the detector results in this sign of acceleration. (**Hint**: Look at how the velocity is changing.)

Question 3-9: When an object is speeding up, what must be the direction of the acceleration relative to the direction of object's velocity? Are they in the same or different directions? Explain.

Question 3-10: The diagram shows the positions of the cart at equal time intervals. At each indicated time, sketch a vector above the cart that might represent the velocity of the cart at that time while it is moving toward the motion detector and speeding up.

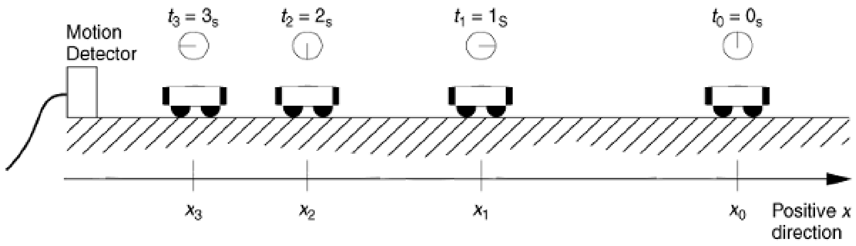


Question 3-11: Show below how you would find the vector representing the change in velocity between the times 1 and 2 s in the diagram above. Based on the direction of this vector and the direction of the positive *x* axis, what is the sign of the acceleration? Does this agree with your answer to Question 3-8?

Question 3-12: Was your general rule in Question 3-6 correct? If not, modify it and restate it here.

Question 3-13: There is one more possible combination of velocity and acceleration directions for the cart: moving *toward* the detector and *slowing down*. Use your general rule to predict the direction and sign of the acceleration in this case. Explain why the acceleration should have this direction and this sign in terms of the sign of the velocity and how the velocity is changing.

Question 3-14: The diagram shows the positions of the cart at equal time intervals for the motion described in Question 3-13. At each indicated time, sketch a vector above the cart that might represent the velocity of the cart at that time while it is moving toward the motion detector and slowing down.



Question 3-15: Show how you would find the vector representing the change in velocity between the times 1 and 2 s in the diagram above. Based on the direction of this vector and the direction of the positive *x* axis, what is the sign of the acceleration? Does this agree with your answer to Question 3-13?

If you have more time, do the following Extension.

Extension 3-3: Graphing Slowing Down Toward the Motion Detector

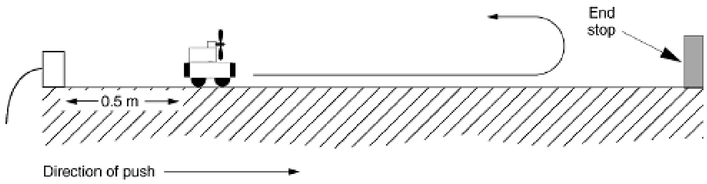
Use the motion detector setup to graph the motion of the cart moving *toward* the motion detector and *slowing down*, as described in Question 3-13.

Question E3-16: Compare the graphs to your answers to Questions 3-13 to 3-15.

Activity 3-4: Reversing Direction

In this activity you will look at what happens when the cart slows down, reverses its direction and then speeds up in the opposite direction. How does the velocity change with time? What is the cart's acceleration?

The setup should be as shown below–the same as before. The fan unit should have the maximum number of batteries, and should be taped securely to the cart.



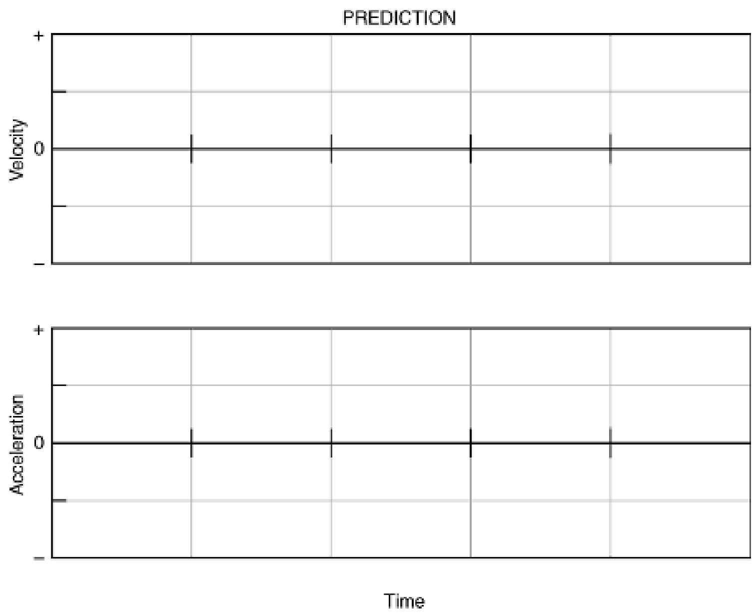
Prediction 3-3: You start the fan and give the cart a push *away* from the motion detector. It moves away, slows down, reverses direction, and then moves back

toward the detector. Try it without using the motion detector! *Be sure to stop the cart before it hits the motion detector, and turn the fan off immediately*.

For each part of the motion–*away from the detector, at the turning point*, and *toward the detector*–indicate in the table below whether the velocity is positive, zero, or negative. Also indicate whether the acceleration is positive, zero, or negative.

	Moving away	At the turning point	Moving toward
Velocity			
Acceleration			

On the axes that follow sketch your predictions of the velocity—time and acceleration—time graphs of this entire motion.

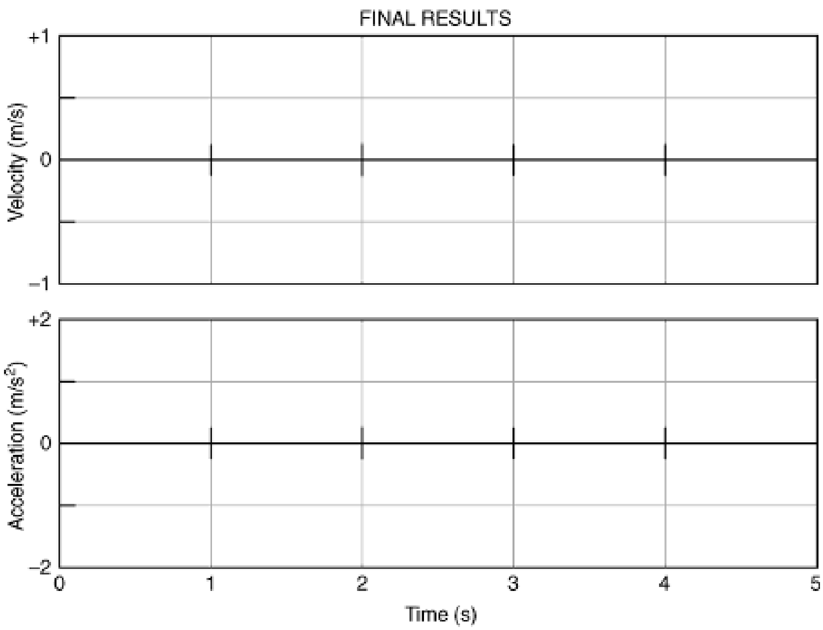


1. Test your predictions. Set up to graph velocity and acceleration on the following graph axes. (Open the experiment file called **Slowing Down (L2A3-1)** if it is not already opened.)

2. **Begin graphing** with the back of the cart near the 0.5-m mark. Turn on the fan unit, and when you begin to hear the clicks from the motion detector, give the cart a gentle push away from the detector so that it travels at least 1 m, slows down, and then reverses its direction and moves toward the detector. (*Push and stop the cart with your hand on its side. Be sure that your hand is not between the cart and the detector.*)

Be sure to stop the cart at least 0.5-m from the motion detector and turn off the fan unit immediately.

You may have to try a few times to get a good round trip. Don't forget to change the scales if this will make your graphs clearer.



3. When you get a good round trip, sketch both graphs on the axes above or **print** and affix over the axes.

Question 3-17: Label *both* graphs with

- A where the cart started being pushed.
- B where the push ended (where your hand left the cart).
- C where the cart reached its turning point (and was about to reverse direction).
- D where you stopped the cart.

Explain how you know where each of these points is.

Question 3-18: Did the cart "stop" at its turning point? (**Hint**: Look at the velocity graph. What was the velocity of the cart at its turning point?) Does this agree with your prediction? How much time did it spend at the turning point velocity before it started back toward the detector? Explain.

Question 3-19: According to your acceleration graph, what is the acceleration at the instant the cart reaches its turning point? Is it positive, negative, or zero? Is it significantly different from the acceleration during the rest of the motion? Does this agree with your prediction?

Question 3-20: Explain the observed sign of the acceleration at the turning point. (**Hint**: Remember that acceleration is the *rate of change* of velocity. When the cart is at its turning point, what will its velocity be in the next instant? Will it be positive or negative?)

Question 3-21: On the way back toward the detector, is there any difference between these velocity and acceleration graphs and the ones that were the result of the cart starting from rest (Activity 3-2)? Explain.

If you have more time, do the following Extension.

Extension 3-5: Sign of Push and Stop

Find on your acceleration graphs for Activity 3-4 the time intervals when you pushed the cart to start it moving and when you stopped it.

Question E3-22: What is the sign of the acceleration for each of these intervals? Explain why the acceleration has this sign in each case.

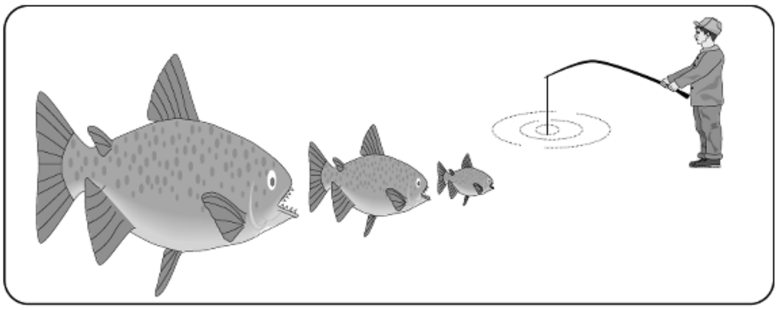
Challenge: You throw a ball up into the air. It moves upward, reaches its highest point, and then moves back down toward your hand. Assuming that upward is the positive direction, indicate in the table that follows whether the velocity is positive, zero, or negative during each of the three parts of the motion. Also indicate if the acceleration is positive, zero, or negative. (**Hint**: Remember that to find the acceleration, you must look at the *change in* velocity.)

	Moving up *after release*	At highest point	Moving down
Velocity			
Acceleration			

Question 3-23: In what ways is the motion of the ball similar to the motion of the cart that you just observed? What causes the ball to accelerate?

Name___________________________________Date_______________________Partners_________________________________

LAB 5: FORCE, MASS, AND ACCELERATION



". . . equal forces shall effect an equal change in equal bodies . . ."

–I. Newton

OBJECTIVES

- To develop a definition of mass in terms of an object's acceleration under the influence of a force.
- To find a mathematical relationship between the acceleration of an object and its mass when a constant force is applied–*Newton's second law*.
- To examine the mathematical relationship between force, mass, and acceleration–*Newton's second law*–in terms of the SI units (N for force, kg for mass, and m/s^2 for acceleration).
- To develop consistent statements of *Newton's first* and *second laws of motion* for one-dimensional motion (along a straight line) for any number of one-dimensional forces acting on an object.

OVERVIEW

In this lab you will continue to develop the first two of Newton's famous laws of motion. You will do this by combining careful definitions of force and mass with observations of the mathematical relationships among these quantities and acceleration.

You have seen that the acceleration of an object is directly proportional to the *combined* or net force acting on the object. If the combined force is not zero, then the object will accelerate. If the combined force is constant, then the acceleration is also constant. These observations can be summarized by *Newton's second law of motion*.

In Lab 4, you have also seen that for an object to move at a constant velocity (zero acceleration) when friction is negligible, the combined or net force on the object is zero. (You will see later that friction can be treated as a force and included in the calculation of net force.) The law that describes constant velocity motion of an object is *Newton's first law of motion*. Newton's first and second laws of motion are very powerful! They allow you to relate the net force on an object to its subsequent motion, and to make mathematical predictions of the object's motion.

What if a force were applied to an object having a larger mass? A smaller mass? How would this affect the acceleration of the object? In Investigation 1 of this lab you will study how the amount of "stuff" (mass) experiencing a force affects the magnitude of its acceleration.

In Investigation 2 you will study more carefully the definitions of the units in which we express force, mass, and acceleration.

INVESTIGATION 1: FORCE, MASS AND ACCELERATION

In previous activities you have applied forces to a cart having the same mass in each case and examined its motion. But when you apply a force to an object, you know that the object's mass has a significant effect on its acceleration. For example, compare the different accelerations that would result if you pushed a 1000-kg (metric ton) automobile and a 1-kg cart, with the same force!

In this investigation you will explore the mathematical relationship between acceleration and mass when you apply the same constant force to carts of different mass.

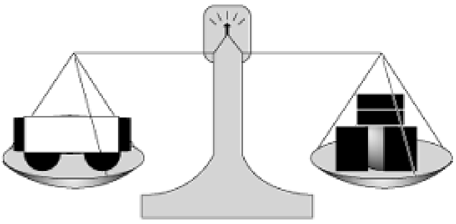
You will need

- computer-based laboratory system
- motion software
- *RealTime Physics Mechanics experiment* configuration files
- force probe
- motion detector
- low-friction cart of mass about 0.5 kg
- variety of masses to increase the mass of the cart, totaling 2—3 times the mass of the cart
- spring scale with a maximum reading of 5 N
- equal arm (two pan) balance
- smooth ramp or other level surface 2—3 m long
- low-friction pulley and string
- variety of hanging masses (10—50 g)

Activity 1-1: Acceleration and Mass

You can easily change the mass of the cart by attaching masses to it, and you can apply the same force each time by using a string attached to appropriate hanging masses. By measuring the acceleration of different mass carts, you can find a mathematical relationship between the acceleration of the cart and its mass, when the force applied by the string is kept constant.

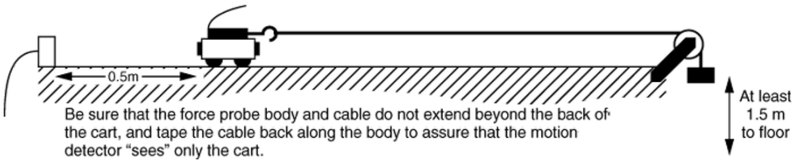
1. Set up the ramp, pulley, cart, string, motion detector, and force probe as shown in the figure that follows. Be sure that the ramp is level.



The force probe should be fastened securely to the cart. (*Be sure that the force probe does not extend beyond the end of the cart*. The cable must not interfere with the motion of the cart and must not be seen by the motion detector.)

2. We will define a mass scale in which the unit is the mass of the cart (*including the force probe*), called one *cart mass*. An equal arm balance can be used to assemble a combination of masses equal to *one cart mass*. If this combination of masses is divided in half, each half is 0.5 cart mass.

   Use the balance in this way to assemble masses that you can add to the cart to make the cart's mass equal to 1.5, 2.0, 2.5, and 3.0 cart masses. Label these masses.



3. Now add enough masses to make the cart's mass 2.0 cart masses.

4. Be sure that the cart's friction is minimum. (If the cart has a friction pad, it should be raised so that it doesn't contact the ramp.)

5. Find a hanging mass that will accelerate the cart across the track from left to right in about 2—3 s as it is falling.

   Record the value of this mass:______kg

6. **Calibrate** the force probe with a 2.00-N pull or **load the calibration.** (If you are using a Hall effect force probe, you may need to adjust the spacing and **check the sensitivity**.)

7. Open the experiment file called **Acceleration & Mass (L5A1-1)** to display the axes that follow.

8. As always, **zero** the force probe before each graph with nothing pulling on it. **Begin graphing**. Release the cart from rest when you hear the clicks of the motion detector.

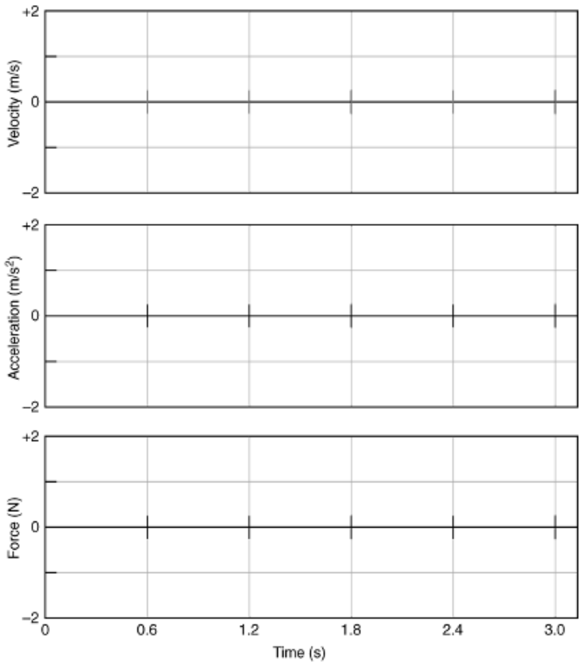
   Move your data so that the graph is **persistently displayed on the screen** for later comparison.

   Sketch your graphs on the axes that follow, or **print** them and affix them over the axes.

9. Use arrows to mark the time interval during which the acceleration is nearly constant on your graph. Use the **analysis and statistics features** of the software to measure the average force experienced by the cart and average acceleration *during the save time interval*. Record your measured values for average force and average acceleration in the third row of Table 1-1.

Table 1-1

Mass of cart(cart masses)	Average applied force (N)	Average acceleration (m/s^2)
1.0		
1.5		
2.0		
2.5		
3.0		



Activity 1-2: Accelerating a Cart With a Different Mass

Prediction 1-1: Suppose that you remove mass from the cart until it is 1.0 cart mass, and accelerate it *with the same applied force*. Compare the acceleration to that of the larger mass cart.

1. Test your prediction. Remove the masses you added in Activity 1-1 that doubled the mass of the cart to 2.0 cart masses.

Comment: You want to accelerate the cart with the *same applied force*. As you may have noticed, the force applied to the force probe by the string decreases once the cart is released. (You will explore why this is so in a later lab.) This decrease depends on the size of the acceleration. Therefore, in order to keep the applied force constant, you may need to change the hanging mass slightly.

2. **Zero** the force probe with no force on it. Adjust the hanging mass until the force probe reading *while the cart is accelerating* is the same as the force you recorded in the third row of Table 1-1.

When you have found the correct hanging mass, graph the motion of the cart. (Don't forget to **zero** the force probe first.) Measure the average force and average acceleration of the cart *during the time interval when the force and acceleration are nearly constant* and record these values in the first row of Table 1-1.

Question 1-1: Did the acceleration agree with your prediction? Explain.

3. Now make the mass of the cart 1.5 cart masses, and accelerate it again *with the same size force*. (Don't forget to adjust the hanging mass, if necessary.) Measure the average force and acceleration of the cart, and record these values in the table.

4. Repeat for masses of 2.5 and 3.0 cart masses.

If you have more time, do the following Extension now, and take additional data for larger masses of the cart.

Extension 1-3: More Data for Larger Masses

Find the average acceleration for the cart with the same average applied force but for masses larger than 3.0 cart masses. Include these data in your graph in Activity 1-4.

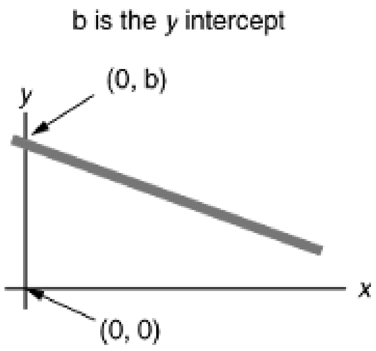
Activity 1-4: Relationship Between Acceleration and Mass

1. Plot a graph of average acceleration vs. cart mass (with constant applied force). You can do this by opening the experiment file called **Avg. Accel. vs. Mass (L5A1-4).** Enter the acceleration and mass data into the table on the screen. You may wish to **adjust the axes** to better display the data.

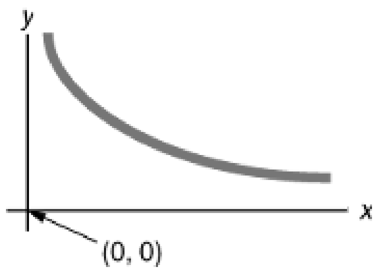
Question 1-2: Does the acceleration of the cart increase, decrease, or remain the same as the mass of the cart is increased?

Comment: We are interested in the nature of the mathematical relationship between average acceleration and mass of the cart, with the applied force kept constant. As always, this can be determined from the graph by drawing a smooth curve which fits the plotted data points.

Some definitions of possible mathematical relationships when *y* decreases as x increases are shown in the sketches below. In these examples, *y* might be the average acceleration, and x the mass of the cart.



y is a *linear* function, which decreases linearly as x increases according to the relationship
mathematical relationship $y = mx + b$, where the slope m is a negative constant and *b* 5 const.



y is a function of *x*, which decreases as *x* increases. The mathematical

might be $y = b + cx^{-n}$, where n is an integer. When b = 0 and n = 1, the relationship becomes $y = c/x$, and *y* is said to be inversely proportional to x.

Note that these *are not all the same*. *y* can decrease as *x* increases, and the relationship doesn't have to be *linear* or *inversely proportional. Inverse proportionality* refers *only* to the special relationship where $y = c/x$, where *c* is a constant. The motion software allows you to determine the relationship by trying various curves to see which best fits the plotted data.

2. Use the fit routine in the software to fit the data on your graph of average acceleration vs. mass of the cart. Select various possible relationships and test them.

3. When you have found the best fit, **print** the graph along with the fit equation and affix it below.

Question 1-3: What appears to be the mathematical relationship between acceleration and mass of the cart, when the applied force is kept constant?

Question 1-4: In the previous lab, you found that the acceleration of the cart was proportional to the *combined* applied force when the mass of the cart was not changed. State in words the general relationship between the applied force, the mass, and the acceleration of the cart that you have found in these two labs. If the combined force is $\sum \vec{\mathbf{F}}_1$, the mass is *m*, and the acceleration is $\vec{\mathbf{a}}$,write a mathematical relationship that relates these three physical quantities.

If you have more time, do the following Extension.

Extension 1-5: Acceleration vs. Mass for a Different Applied Force

Prediction E1-2: Suppose that you applied a larger force to the cart by using a hanging mass twice as large as before. How would the relationship between average acceleration and mass compare to that in Activity 1-4? In what ways would it be similar and in what ways would it be different?

Test your prediction. Repeat Activities 1-1 through 1-4, this time using a hanging mass twice as large to accelerate the cart.

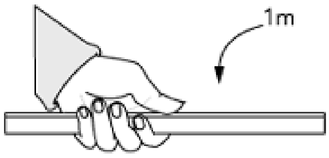
Plot a graph of average acceleration vs. mass, as in Activity 1-4 and determine the relationship between acceleration and mass.

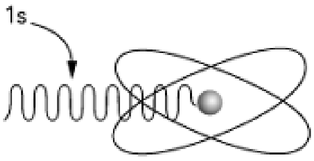
Question E1-5: Compare the relationship between acceleration and mass with this larger constant applied force to the one for the smaller applied force you used before. Is this what you expected?

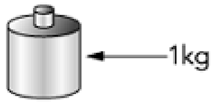
INVESTIGATION 2: FORCE AND MASS UNITS

So far you have been measuring force in *standard* units based on the pull exerted by a spring scale calibrated in newtons. Where does this unit come from? By contrast, we have our own private units for measuring mass–cart masses. If one group were using a large wooden cart in their force and motion experiments and another group were using a small aluminum cart with smaller mass, they would have different values for mass and would observe different accelerations for "one cart mass pulled by one newton." It's time to discuss standard units for force and mass.

It would be nice to be able to do a mechanics experiment in one part of the world and have scientists in another part of the world be able to replicate it or at least understand what actually happened. This requires that people agree on standard units. In 1960 an international commission met to develop a common set of units for fundamental quantities such as length, time, mass, force, electric current, and pressure. This commission agreed that the most fundamental units in the study of mechanics are those of length, time, and mass. All other units, including those of force, work, energy, torque, and rotational velocity, that you encounter in your study of mechanics can be expressed as a combination of these basic quantities. The fundamental *International System* or *SI* units along with the standard unit for force are shown in the boxes below.





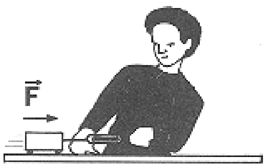


FUNDAMENTAL UNITS FOR MECHANICS

Length: A **meter (m)** is the distance traveled by light in a vacuum during a time of 1/299,792,458 s.

Time: A **second (s)** is defined as the time required for a cesium-133 atom to undergo 9,192,631,770 vibrations.

Mass: A **kilogram (kg**) is defined as the mass of a platinum—iridium alloy cylinder kept at the International Bureau of Weights and Measures in SŽvres, France. It is kept in a special chamber to prevent corrosion.



$1\ N = 1\ kg \cdot m/s^2$

THE FORCE UNIT EXPRESSED IN TERMS OF LENGTH, MASS, AND TIME

Force: A **newton (N)** is defined as that force which causes a 1-kg mass to accelerate at 1 m/s^2.

We want to be able to measure masses in kilograms and forces in newtons in our own laboratory. The following activities are designed to give you a feel for standard mass and force units and how they are determined in the laboratory. You will need the following equipment:

- computer-based laboratory system
- motion software
- *RealTime Physics Mechanics* experiment configuration files
- force probe
- motion detector
- balance or electronic scale to measure masses in kilograms
- spring scale with a maximum reading of 5 N
- low-friction cart
- smooth ramp or other level surface 2—3 m long
- low-friction pulley and string
- assortment of hanging masses (10—50 g)

Our approach in the following activities is to use a standard force scale to calibrate the force probe in newtons. Using your data from the previous investigation, you will see how you can establish a mass unit in terms of your force and acceleration measurements. Then you will use a standard mass scale to get enough stuff loaded on a cart to equal one kilogram of mass. Finally, you can pull the cart with a force of about one newton and see if it accelerates at something close to one meter per second squared.

WARNING! There will probably be a noticeable amount of uncertainty associated with your measurements.

Suppose you want to find the mass of an object in kilograms. You need to compare it to the 1-kg platinum—iridium alloy cylinder at the International Bureau of Weights and Measures in France. It would be nice to have a standard kilogram in your laboratory. You could go to France, but it is unlikely that they would let you take the standard home with you!

Suppose, however, that you go to France and accelerate the *standard* mass with a constant force and measure the force and also the resulting acceleration as accurately as possible. Next you would need to make a cylinder that seemed just like the standard one and add or subtract stuff from it until it undergoes *exactly the same acceleration with the same constant force*. Then within the limits of experimental uncertainty this new cylinder standard and the bureau standard would have the same mass. If the comparison could be made to three significant figures, then the mass of your new standard would be m_{std} = 1.00 kg.

Suppose you head home with your standard mass. You wish to determine the mass of another object. You could apply the same constant force F on the standard and on the other object, and measure both accelerations. Then, according to *Newton's second law, F = ma,*

$$m_{\text{std}} = 1.00\,\text{kg} = \frac{F}{a} \qquad m_{\text{other}} = \frac{F}{a_{\text{other}}}$$

Since the constant force, *F*, applied to both masses was the same,

$$m_{\text{other}} = 1.00\text{kg}\frac{a}{a_{\text{other}}}$$

In fact, you already did something similar in the last investigation.

Activity 2-1: Calculating One "Cart Mass" in Standard Units

1. In Investigation 1 of this lab, you measured the force applied to a cart and the acceleration of the cart with mass equal to 1.0, 1.5, 2.0, 2.5, and 3.0 cart masses. Turn back to Table 1-1 from that experiment and copy the values of average force and average acceleration into the second and third columns of Table 2-1.

Table 2-1

Mass of cart (cart masses)	Average applied force (N)	Average acceleration (m/s^2)	Ratio of *F/a* (calculated mass)	Mass of cart measured with balance (kg)
1.0				
1.5				
2.0				
2.5				
3.0				

In the discussion above, the mass in standard units was calculated using Newton's second law by taking the ratio of the combined (net) force on the object in newtons to the acceleration of the object measured in meters per second squared.

2. For each row in Table 2-1, calculate the ratio of the force to acceleration and record it in the fourth column.

Question 2-1: According to the discussion, the values you just calculated should be the masses of the objects in kilograms. Do your numbers seem to make sense? What do you get for the value of 1.00 cart mass in kilograms? What do you get for the value of 2.00 cart masses in kilograms?

Comment: Physicists call the quantity you have just calculated–the ratio of combined (net) force on an object to its acceleration–the *inertial mass* of the object.

You could continue to determine and compare masses by accelerating them and taking force to acceleration ratios, but this process is pretty tedious. A simpler approach is to use an electronic scale or a mechanical balance that has already been calibrated in kilograms by somebody who is intelligent and knowledgeable using a standard mass! (The details of why such devices can give us correct masses in kilograms will not be easy to understand fully until after gravitational forces are studied in Lab 6.)

3. Compare your inertial mass calculations for 1.0, 1.5, 2.0, 2.5, and 3.0 cart masses with the values you get by placing your cart on an electronic scale or mechanical balance. Record these values in the last column of Table 2-1.

Question 2-2: Are your inertial masses reasonably consistent with your masses measured with the scale or balance?

Comment: In your experiments, you have seen that the physical quantities force, mass and acceleration are related through *Newton's second law*. In the activity you have just done, you have used this relationship to *define* inertial mass in terms of *standard* units of force, length, and time. This is a good logical definition of inertial mass.

Historically, however, the units of mass, length, and time were defined first as *standards* and the unit of force was defined as a *derived* unit in terms of these standard units. Thus, *a newton of force is defined as the force needed to accelerate 1.00 kg at 1.00 m/s*^{2}. In the next activity you will examine this definition.

Activity 2-2: Does a Force of 1.0 N Applied to a 1.0-kg Mass Really Cause an Acceleration of 1.0 m/s^2?

You have used mass and force measuring devices that have been provided for you. You can now see if everything makes sense by accelerating one kilogram of mass with a force of about one newton and seeing if an acceleration of about one meter per second squared results.

1. Set up the ramp, pulley, weighted cart, string, motion detector, and force probe as in Activity 1-1.

Tape masses to the cart along with the force probe so that the total mass of the cart is 1.0 kg.

Be sure that the cable from the force probe doesn't interfere with the motion of the cart and is out of the way of the motion detector.

2. Open the experiment file called **Acceleration with 1.0 N Force (L5A2-2)** to set up axes to graph velocity, acceleration, and force.

3. **Calibrate** the force probe with a force of 2.0 N using the spring scale or **load the calibration**, if it hasn't already been calibrated. (If you are using a Hall effect force probe, be sure to **check the sensitivity** of the force probe before you calibrate.)

4. Remember to **zero** the force probe with nothing pulling on it before each run. Measure the acceleration that results from a 1.0-N force applied to the force probe. Try different hanging masses until you get an applied force of close to 1.0 N *while the cart is accelerating*.

Comment: *Be careful*! Remember that when the cart is being held at rest, the same hanging mass will exert more applied force on the cart than when it is accelerating.

5. Once you get a good run, use the **analysis and statistics features** of the software to measure the average values of force and acceleration, and record these values in the table below. Also record the hanging mass.

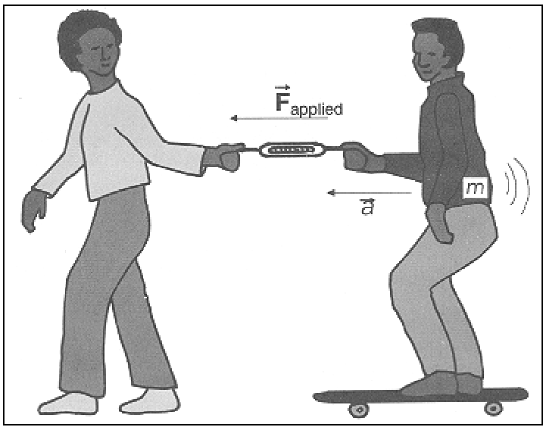
Mass of cart (kg)	
Average applied force (N)	
Average acceleration (m/s^2)	
Hanging mass (kg)	

Question 2-3: How close is your result to the expected value of acceleration–1.0 m/s^2? Discuss sources of uncertainty in your measurements of acceleration and force.

Question 2-4: A force of 5.4 N is applied to an object, and the object is observed to accelerate with an acceleration of 3.0 m/s^2. If friction is so small that it can be ignored, what is the mass of the object in kilograms? Show your calculation.

Question 2-5: An object of mass 39 kg is observed to accelerate with an acceleration of 2.0 m/s^2. If friction is so small that it can be ignored, what is the force applied to the object in newtons? Show your calculation.

Comment: The main purpose of Labs 3, 4, and 5 has been to explore the relationship between the forces on an object, its mass, and its acceleration. You have been developing *Newton's first and second laws of motion* for one-dimensional situations in which all forces lie in a positive or negative direction along the same line.



Activity 2-3: Newton's Laws in Your Own Words

Question 2-6: Express Newton's first law (the one about constant velocity) in terms of the *combined (net)* force applied to an object in your own words clearly and precisely.

Question 2-7: Express *Newton's first law* in equations in terms of the acceleration vector, the *combined (net)* force vector applied to an object, and the object's mass.

If $\sum \vec{\mathbf{F}} =$ then $\vec{\mathbf{a}}$ and $\vec{\mathbf{v}} =$

Question 2-8: Express *Newton's second law* (the one relating force, mass, and acceleration) in terms of the *combined (net)* force applied to an object in your own words clearly and precisely.

Question 2-9: Express *Newton's second law* in equations in terms of the acceleration vector, the *combined (net)* force vector applied to an object, and its mass.

If $\sum \vec{\mathbf{F}} \neq 0$ then $\vec{\mathbf{a}} =$

Comment: The use of the equal sign in the mathematical representation of Newton's second law does not signify that an acceleration is the same as or equivalent to a force divided by a mass, but instead it spells out a procedure for calculating the magnitude and direction of the acceleration of a mass while it is experiencing a net force. What we assume when we subscribe to *Newton's second law* is that a net force on a mass *causes* an acceleration of that mass.

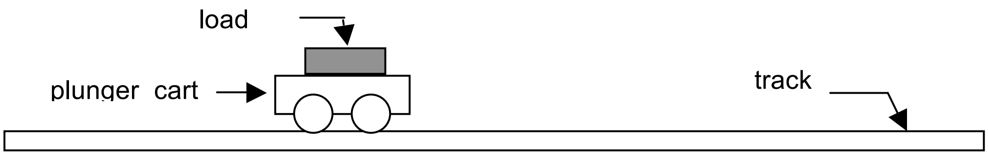
Prepared by Ivan Culaba, Ateneo de Manila University, Philippines (Worksheets: Demos 1-5 of 7)

Name: ______________________________

Section: ______________________________

Interactive Lecture Demonstration
Conservation of Momentum / Elastic Collisions
Prediction Sheet

Demonstration 1: The cart with a load is moving along the track at constant velocity. Predict what happens to the cart when its load is suddenly removed.



Your prediction:

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Your group's prediction:

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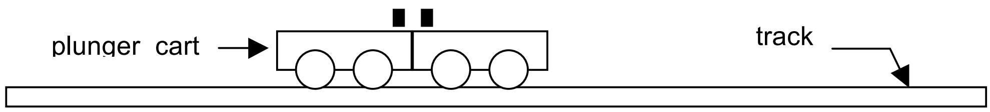
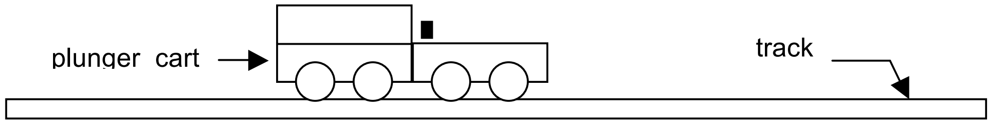
Demonstration 2: The two carts with plungers are initially at rest on the track. The carts' plungers are completely latched and the two carts are placed against each other. Predict the relative speeds of the car when the plunger explodes.



Your prediction: ____

Your group's prediction: ____

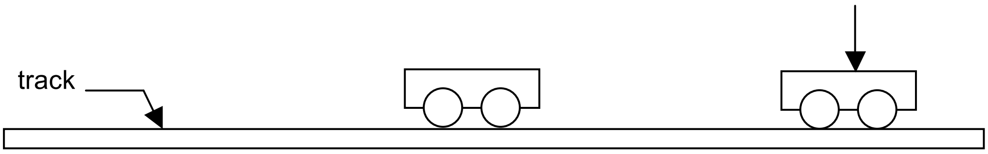
Demonstration 3: One cart has twice the mass of the other. They are initially at rest at the middle of the track. With their plungers completely latched, the two carts are placed against each other. Predict the relative speeds of the carts when the plunger is released.



Your prediction: ____

Your group's prediction: ____

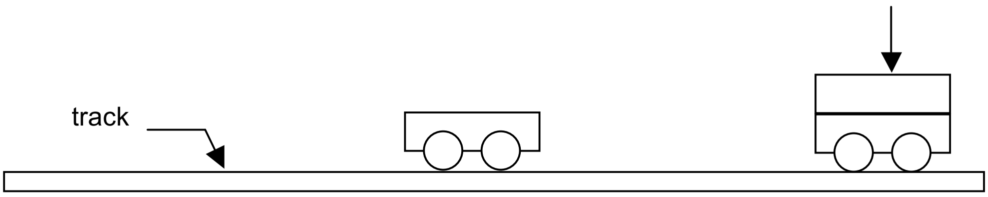
Demonstration 4: One of the collision carts is placed at one end of the track while the other collision cart is placed at rest in the middle of the track. The cart at the end of the track is pushed forward so that it makes an elastic collision with the other cart Predict what happens to the carts after the collision.



Your prediction: ____

Your group's prediction: ____

Demonstration 5: Some mass is added to the collision cart. The more massive cart is placed at one end of the track while the other collision cart is placed at rest in the middle of the track. The more massive cart is pushed forward so that it makes an elastic collision with the other cart. Predict what would happen to the carts after the collision.



Your prediction : ____

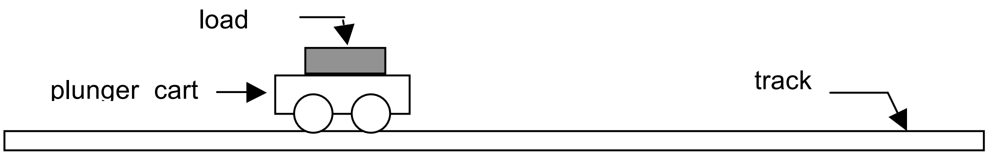
Your group's prediction: ____

Name: ______________________________

Section: ______________________________

Interactive Lecture Demonstration
Conservation of Momentum / Elastic Collisions
Results Sheet

Demonstration 1: The cart with a load is moving along the track at constant velocity. Predict what happens to the cart when its load is suddenly removed.



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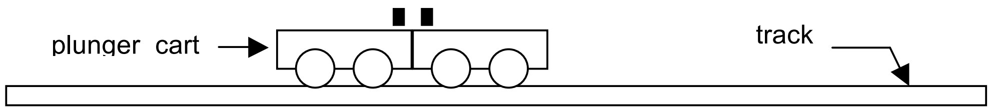
Demonstration 2: The two carts with plungers are initially at rest on the track. The carts' plungers are completely latched and the two carts are placed against each other. Predict the relative speeds of the car when the plunger explodes.



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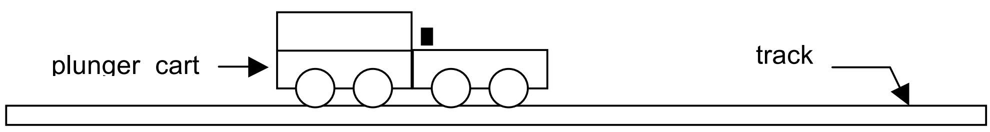
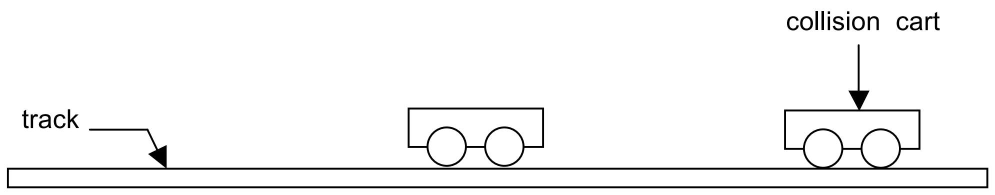
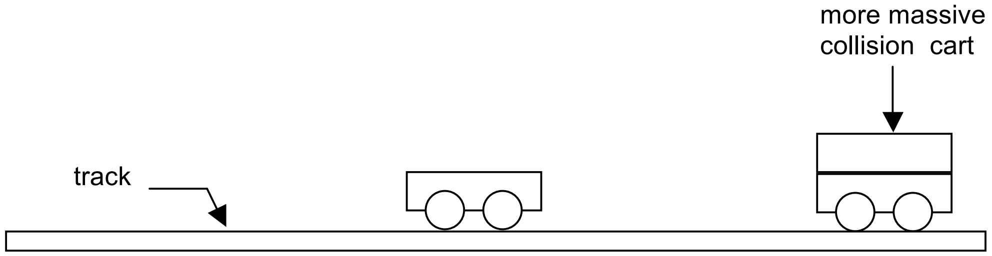
Demonstration 3: One cart has twice the mass of the other. They are initially at rest at the middle of the track. With their plungers completely latched, the two carts are placed against each other. Predict the relative speeds of the carts when the plunger is released.



Demonstration 4: One of the collision carts is placed at one end of the track while the other collision cart is placed at rest in the middle of the track. The cart at the end of the track is pushed forward so that it makes an elastic collision with the other cart Predict what happens to the carts after the collision.



Demonstration 5: Some mass is added to the collision cart. The more massive cart is placed at one end of the track while the other collision cart is placed at rest in the middle of the track. The more massive cart is pushed forward so that it makes an elastic collision with the other cart. Predict what would happen to the carts after the collision.



Prepared by Ivan Culaba, Ateneo de Manila University, Philippines

Interactive Lecture Demonstration
Conservation of Linear Momentum and Elastic Collisions
Teacher's Presentation Notes

Theory:

The net external force $\Sigma \mathbf{F}_{ext}$ acting on an system of particles is equal to the rate of change of the system's total momentum $\mathbf{P}$:

$$\Sigma \mathbf{F}_{ext} = d\mathbf{P} / dt$$

If $\Sigma \mathbf{F}_{ext} = 0$ then $d\mathbf{P} / dt = 0$. This means that the total momentum of the system remains constant in time or the total momentum of the system is conserved. In elastic collisions both the total momentum and the total kinetic energy of the system of particles is conserved.

In this sequence of lecture demonstration experiments the students will predict the motion of a cart and the outcome of different collisions between carts using the conservation of linear momentum.

Materials:

2 identical collision carts with low-friction wheels and built-in magnets for completely elastic collisions
track for the carts
set of weights
2 identical plunger carts with built-in plungers for collisions
1 bar to couple the collision carts

Note: This could also be done using an airtrack.

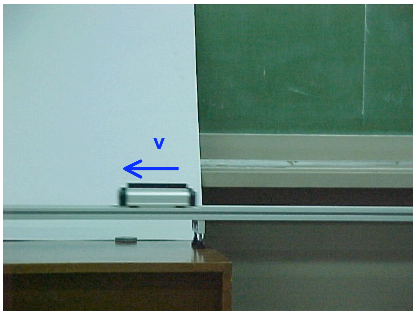


Fig. 1. A cart with a load is moving along the track at constant velocity.

Demonstration 1: The cart with a load is moving along the track at constant velocity (Figure 1). Let the students predict what happens to the cart when its load is suddenly removed.

Expected result: The cart moves faster when the load is removed as shown in Figure 2.

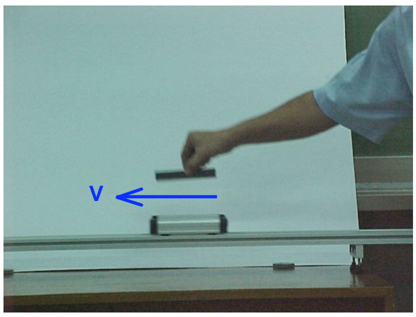


Fig. 2. The car moves faster when the load is removed.

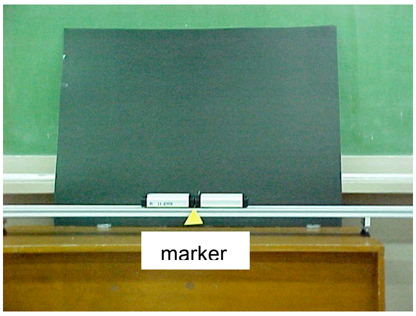


Fig. 3. Two carts of equal masses are initially at rest on the track.

Demonstration 2: Two carts of equal masses are initially at rest on the track (Figure 3). With their plungers completely latched, the two carts are placed against each other. Let the students predict the relative speeds of the carts when the plunger is released.

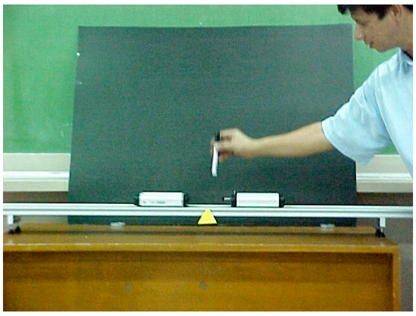


Fig. 4. The plunger is released and the carts move in opposite directions with approximately equal speeds. Note distances covered relative to the marker.

Expected result: The carts move in opposite directions with approximately equal speeds as shown in Figure 4.

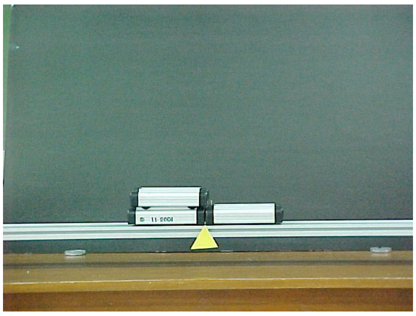


Fig. 5. Two carts of unequal masses are initially at rest in the middle of the track.

Demonstration 3: One cart has twice the mass of the other. They are initially at rest at the middle of the track. With their plungers completely latched, the two carts are placed against each other (Figure 5). Let the students predict the relative speeds of the carts when the plunger is released.

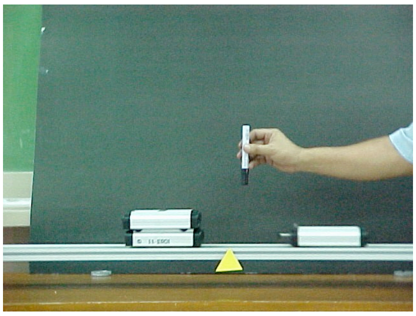


Fig. 6. The two carts move away from each other. The less massive cart will have twice the speed of the other. Note relative distances with respect to the marker.

Expected Result: The two carts will move away from each other. The less massive cart will have twice the speed of the other (Figure 6).

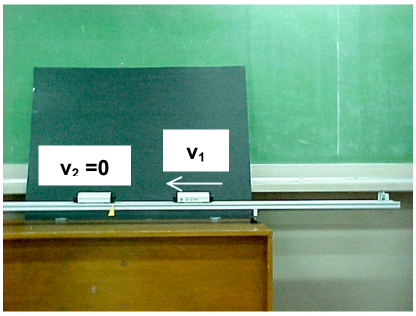


Fig. 7. A cart approaches an identical cart that is initially at rest in the middle of the track.

Demonstration 4: One of the collision carts is placed at one end of the track while the other collision cart is placed at rest in the middle of the track. Push the cart (at the end of the track) so that it makes an elastic collision with the other cart (Figure 7). Let the students predict what happens to the carts after the collision.

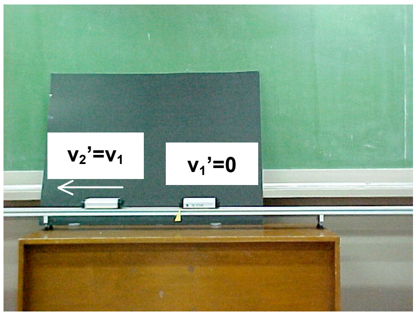


Fig. 8. After the collision, the cart initially moving will come to a stop. The cart that was initially at rest will move with approximately the same speed as that of the initial speed of the other cart.

Expected result: After the collision the cart initially moving will come to a stop. The cart that was initially at rest will move with approximately the same speed as that of the initial speed of the other cart (Figure 8).

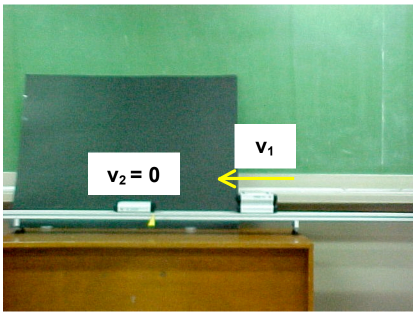


Fig. 9. A massive cart approaches a less massive cart that is initially at rest.

Demonstration 5: Add some mass to the collision cart. Place the more massive cart at one end of the track while the other collision cart is placed at rest in the middle of the track. Push the more massive cart so that it makes an elastic collision with the other cart (Figure 9). Let the students predict what would happen to the carts after the collision.

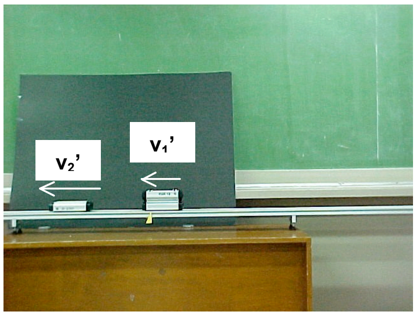


Fig. 10. Both carts move forward but the speed of the massive cart is less than its speed prior to collision.

Expected result: Both carts move forward. However, the speed of the massive cart is less than its speed prior to collision (Figure10).

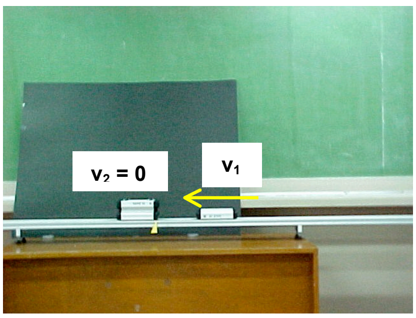


Fig. 11. A light cart approaches a more massive cart that is initially at rest in the

Demonstration 6: Interchange the position of the two carts. The more massive cart is now at the middle of the track and initially at rest. Push the less massive cart so that it makes an elastic collision with the less massive cart (Figure 11). Let the students predict what happens to the cart after the collision.

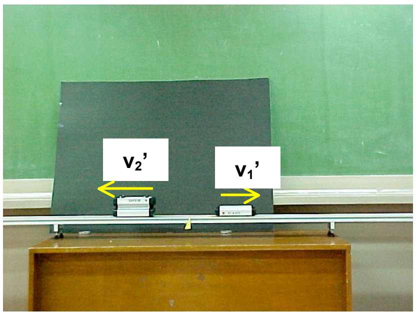


Fig. 12. The more massive cart moves forward while the other cart moves in the opposite direction after the collision.

Expected result: The more massive cart moves forward while the other cart moves in the opposite direction after the collision (Figure 12).

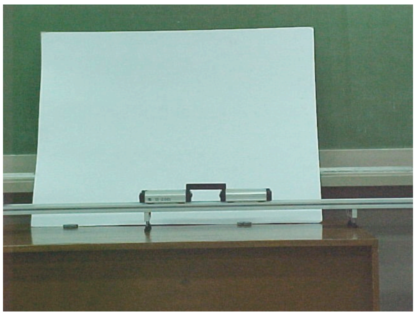


Fig. 13. A bar initially couples two collision carts.

Demonstration 7: A bar temporarily couples the two collision carts (Figure 13). The bar will cause the two carts to move with the same velocity. The tracks are fitted with end stops with magnets for elastic collisions. While the coupled carts are moving with constant velocity the bar is removed (Figure 14). One of the carts collides with the end stop and moves in the opposite direction (Figure 15). It then collides with the other cart. Let the students predict what happens to the carts after their collision.

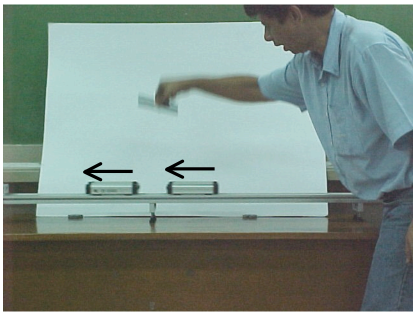


Fig. 14. While the coupled carts are moving with constant velocity the bar is removed.

Expected result: The two carts come to rest after the collision (Figure 16).

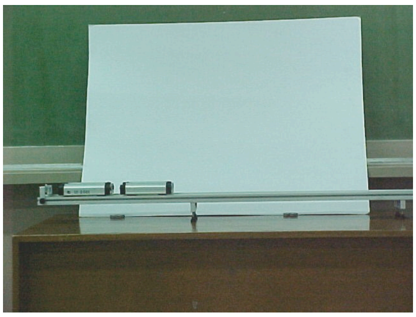


Fig. 15. One of the carts collides with the end stop and moves in the opposite direction.

Name:

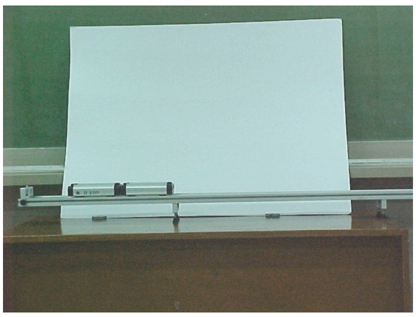


Fig. 16. The two carts come to rest after the collision.

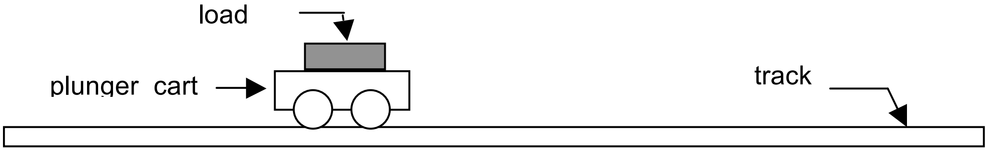
Prepared by Ivan Culaba, Ateneo de Manila University, Philippines

____

Section: ___________________________________

Interactive Lecture Demonstration
Conservation of Momentum / Elastic Collisions
Prediction Sheet

Demonstration 1: The cart with a load is moving along the track at constant velocity. Predict what happens to the cart when its load is suddenly removed.



Your prediction:

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Your group's prediction:

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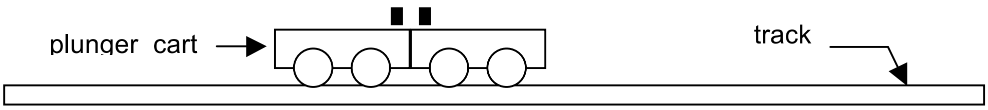
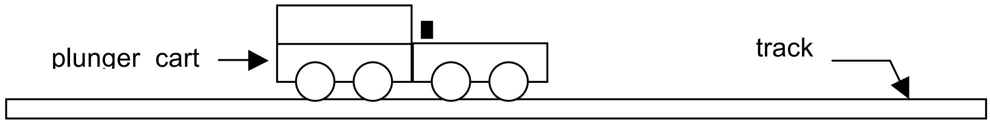
Demonstration 2: The two carts with plungers are initially at rest on the track. The carts' plungers are completely latched and the two carts are placed against each other. Predict the relative speeds of the car when the plunger explodes.



Your prediction: ____

Your group's prediction: ____

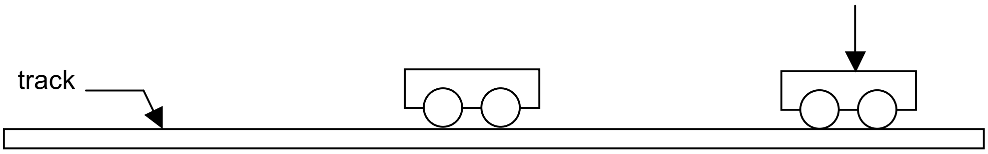
Demonstration 3: One cart has twice the mass of the other. They are initially at rest at the middle of the track. With their plungers completely latched, the two carts are placed against each other. Predict the relative speeds of the carts when the plunger is released.



Your prediction: ____

Your group's prediction: ______________________________________

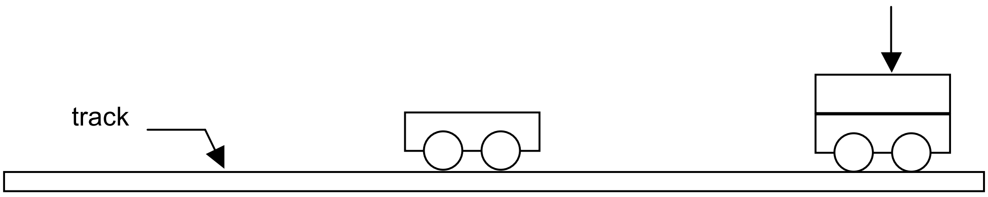
Demonstration 4: One of the collision carts is placed at one end of the track while the other collision cart is placed at rest in the middle of the track. The cart at the end of the track is pushed forward so that it makes an elastic collision with the other cart Predict what happens to the carts after the collision.



Your prediction: ____

Your group's prediction: ______________________________________

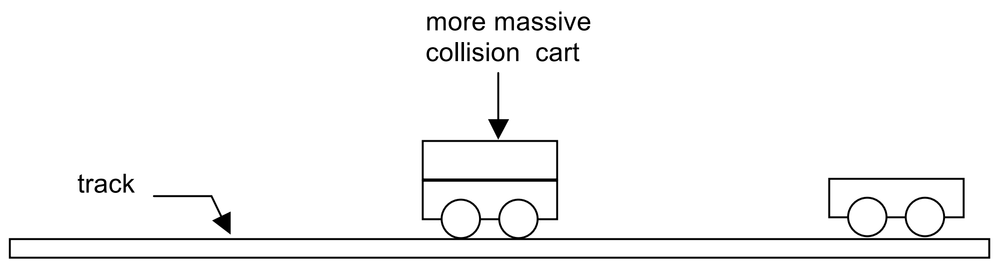
Demonstration 5: Some mass is added to the collision cart. The more massive cart is placed at one end of the track while the other collision cart is placed at rest in the middle of the track. The more massive cart is pushed forward so that it makes an elastic collision with the other cart. Predict what would happen to the carts after the collision.



Your prediction: ____

Your group's prediction: ______________________________________

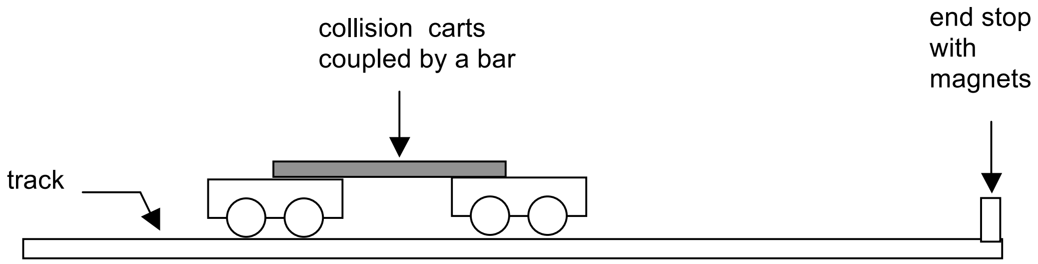
Demonstration 6: The position of the two carts is interchanged. The more massive cart is now at the middle of the track and initially at rest. The less massive cart is pushed forward so that it makes an elastic collision with the less massive cart. Predict what happens to the cart after the collision.



Your prediction: ____________________

Your group's prediction: ____________________

Demonstration 7: A bar temporarily couples the two collision carts. The bar will cause the two carts to move with the same velocity. The tracks are fitted with end stops with magnets for elastic collisions. While the coupled carts are moving with constant velocity the bar is removed. One of the carts collides with the end stop and moves in the opposite direction. It then collides with the other cart. Predict what happens to the carts after their collision.



Your prediction: ____________________

Your group's prediction: ____________________

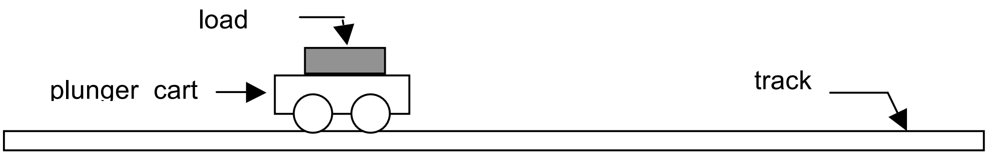
Name: ____________________

Section: ____________________

Prepared by Ivan Culaba, Ateneo de Manila University, Philippines

Interactive Lecture Demonstration
Conservation of Momentum / Elastic Collisions
Results Sheet

Demonstration 1: The cart with a load is moving along the track at constant velocity. Predict what happens to the cart when its load is suddenly removed.



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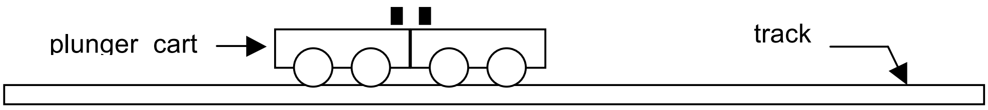
Demonstration 2: The two carts with plungers are initially at rest on the track. The carts' plungers are completely latched and the two carts are placed against each other. Predict the relative speeds of the car when the plunger explodes.



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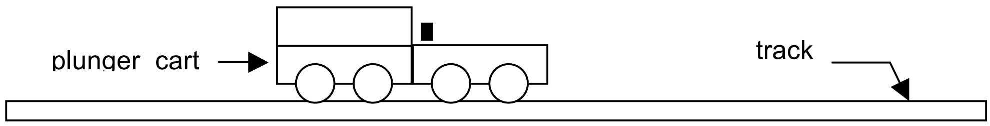
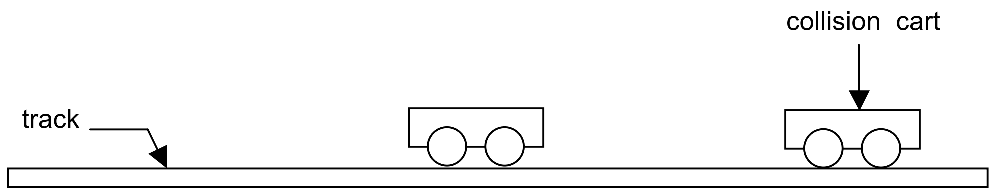
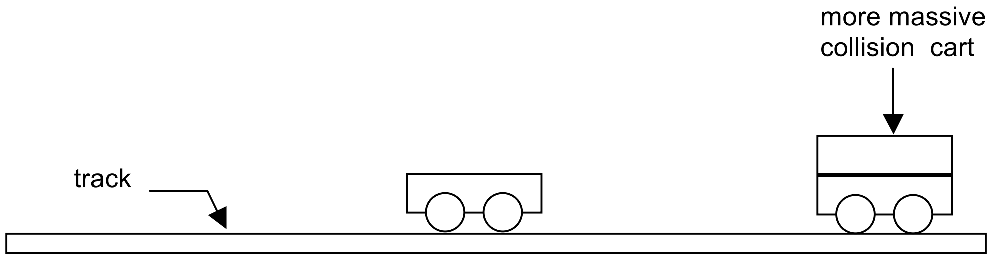
Demonstration 3: One cart has twice the mass of the other. They are initially at rest at the middle of the track. With their plungers completely latched, the two carts are placed against each other. Predict the relative speeds of the carts when the plunger is released.



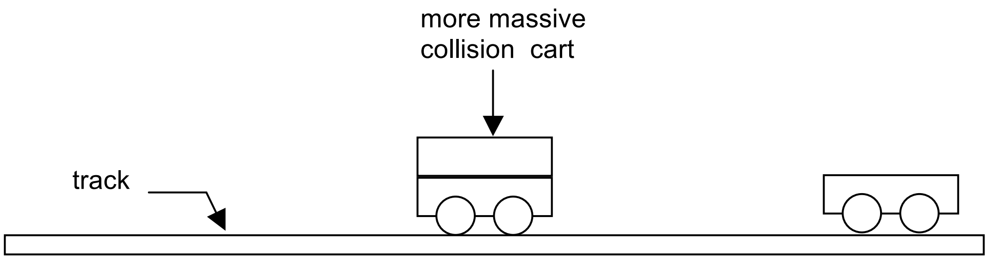
Demonstration 4: One of the collision carts is placed at one end of the track while the other collision cart is placed at rest in the middle of the track. The cart at the end of the track is pushed forward so that it makes an elastic collision with the other cart Predict what happens to the carts after the collision.



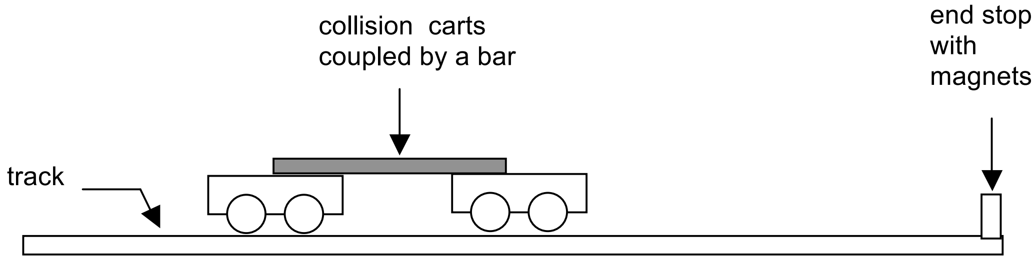
Demonstration 5: Some mass is added to the collision cart. The more massive cart is placed at one end of the track while the other collision cart is placed at rest in the middle of the track. The more massive cart is pushed forward so that it makes an elastic collision with the other cart. Predict what would happen to the carts after the collision.



Demonstration 6: The position of the two carts is interchanged. The more massive cart is now at the middle of the track and initially at rest. The less massive cart is pushed forward so that it makes an elastic collision with the less massive cart. Predict what happens to the cart after the collision.



Demonstration 7: A bar temporarily couples the two collision carts. The bar will cause the two carts to move with the same velocity. The tracks are fitted with end stops with magnets for elastic collisions. While the coupled carts are moving with constant velocity the bar is removed. One of the carts collides with the end stop and moves in the opposite direction. It then collides with the other cart. Predict what happens to the carts after their collision.



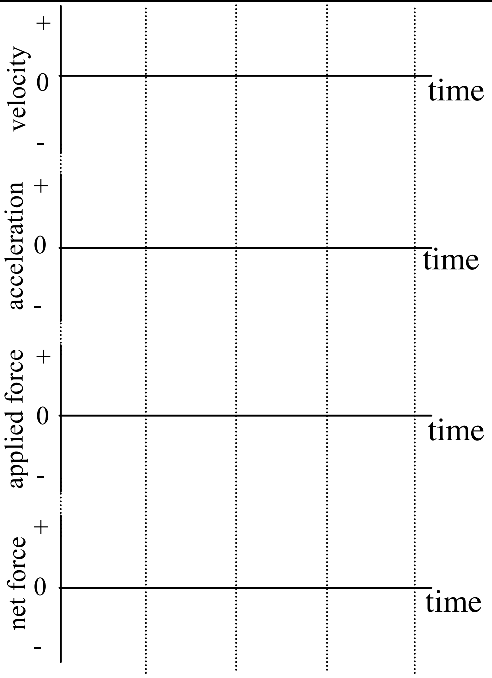
Hand in this sheet **Name**______________________________

INTERACTIVE LECTURE DEMONSTRATIONS
PREDICTION SHEET--**NEWTON'S 1ST & 2ND LAWS**

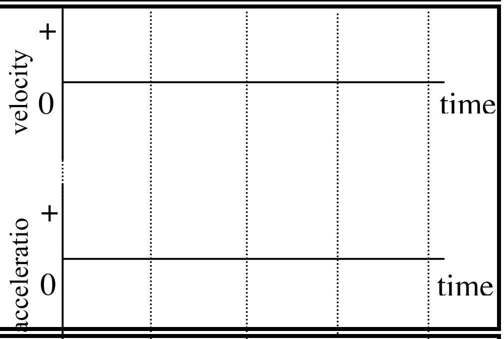
Directions: This sheet will be collected. Write your name at the top to record your presence and participation in these demonstrations. Follow your instructor's directions. You may write whatever you wish on the attached Results Sheet and take it with you.

Demonstration 1: The frictional force acting on the cart is very small (almost no friction) and can be ignored. The cart is pulled with a constant force (the applied force) so that it moves away from the motion detector speeding up at a steady rate (constant acceleration). On the axes to the right sketch your predictions of the velocity and acceleration of the cart and the applied and net force on the cart after it is released and during the time the cart is moving under the influence of the constant force. (Applied and net force are the same in this case. Why?)

Demonstration 2: The frictional force acting on the cart is now increased. The cart is pulled with the same constant force (the applied force) as in Demonstration 1 so that it moves away from the motion detector speeding up at a steady rate (constant acceleration). On the same axes to the right sketch your predictions of the velocity and acceleration of the cart and the applied and net force on the cart after it is released. (Note that the applied and net force are different now. Which determines the acceleration?) We are measuring only the applied force.

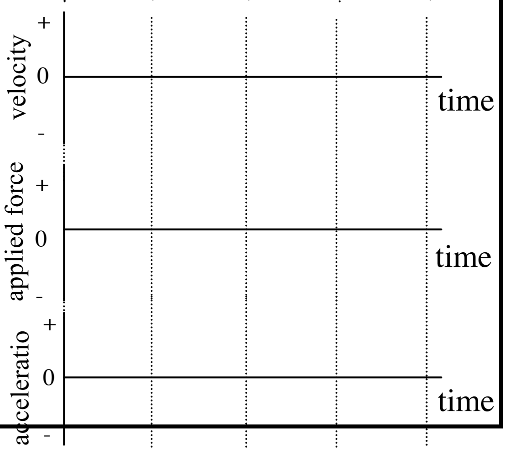


Demonstration 3: The cart has equal and opposite forces acting on it (due to two fans blowing in opposite directions). The frictional force is very small (almost no friction) and can be ignored. The cart is given a quick push away from the motion detector and released. Sketch on the right your predictions of the velocity and acceleration of the cart *after it is released*. What is the net (or resultant) force after it is released?

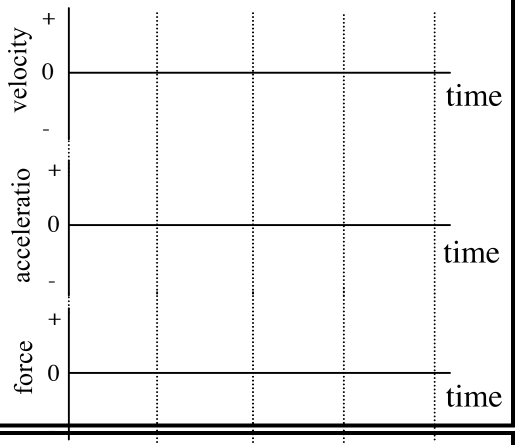


Demonstration 4: The frictional force acting on the cart remains very small (almost no friction). The cart is given a brief pull away from the motion detector and then released. Sketch on the axes on the right your predictions of the velocity and applied force for the motion, *including the time during the pull.* Is the net force the same as the applied force in this case?

What does the acceleration look like? Sketch your prediction on the acceleration-time axes on the right (below the force).



<u>Demonstration 5:</u> The frictional force acting on the cart remains very small (almost no friction) and can be ignored. The cart is given a push toward the motion detector and released. A constant force pulls it in the direction away from the motion detector. The cart moves toward the motion detector slowing down at a steady rate (constant acceleration). Sketch on the axes on the right your predictions of the velocity, acceleration and force for this motion *after the cart is released*. (The applied and the net forces are the same in this case.)

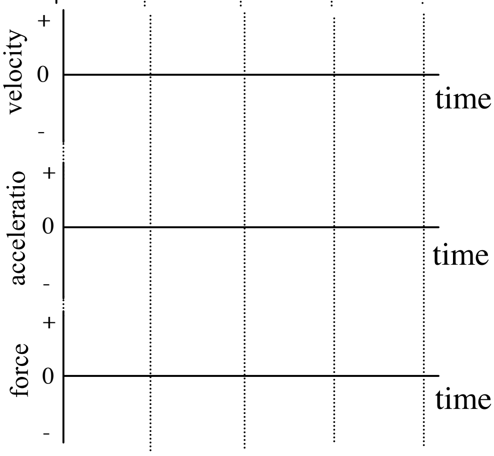


<u>Demonstration 6:</u> The frictional force acting on the cart remains very small (almost no friction) and can be ignored. The cart is given a push toward the motion detector and released A constant force pulls it in the direction away from the motion detector. It moves toward the motion detector slowing down at a steady rate (constant acceleration), comes to rest *momentarily* and then moves away from the motion detector speeding up at a steady rate. Sketch on the axes on the right your predictions of the velocity and acceleration and of the force on the cart *after the cart is released*.

Why is the net force on the cart essentially the same as the applied force in this case?

How does the acceleration at the point the cart reverses direction compare to the acceleration just before it reverses direction?

How does the force at the point the cart reverses direction compare to the force just before it reverses direction?

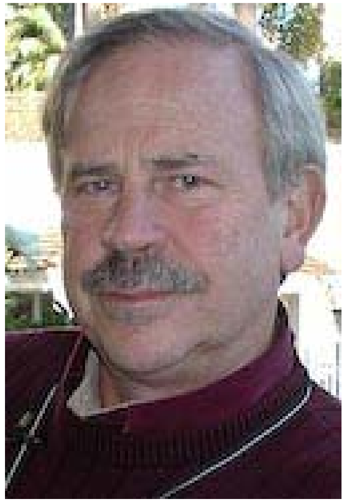


NOTE: We are trying to save paper. In an actual classroom situation the students would have both a prediction sheet and a results sheet. A student would keep the results sheet and give the prediction sheet to the instructor. The student would get points for handing the sheet in as long as it is filled out. IT IS NOT GRADED.

Interactive Lecture Demonstrations (ILDs)

Using Microcomputer-Based Laboratory Tools to achieve active participation in Lecture Sessions

Creators



David Sokoloff
Department of Physics
University of Oregon

Ronald Thornton
Center for Science & Math
Teaching, Tufts University

An active learning environment can be created in a large lecture class or in a small group

Characteristics of an Active Learning Environment

- Construction of knowledge from hands-on observations
- Learning cycle – predictions, observations, comparison and conclusions
- Student control of experiments
- Guided discovery approach
- Encouragement of collaborative, peer learning
- Conceptual and quantitative understanding

A Mechanics ILD w/o Computers

Linear Momentum Conservation
Ivan Culaba, Philippines

Interactive Lecture Demonstration Procedures

1. Describe the demo and do it without measurements.
2. Ask students to record individual predictions on a prediction sheet.
3. Encourage the class to have small group discussions.
4. Ask the class for various predictions.
5. Ask each student to record a final prediction on the Prediction Sheet and collect it at the end of the class session.
6. Do the demonstration and display the measurements.
7. Ask students to describe and discuss the results of the demonstration. Then fill out and keep the Results Sheets.
8. Discuss related physical situations w/ different "surface" features (based on the same concept).

Choosing Experiments for an Interactive Demo Sequence

- The sequence of short, understandable experiments was derived from Physics Education Research (PER).
- Experience with students in hands-on, guided discovery laboratories informed our choice of activities.
- Students must understand (or trust) apparatus used.

*Interactive Lecture Demo Sequences in Mechanics by Sokoloff & Thornton**

- Walking Sequence - Introductory kinematics
- Kinematics Sequence - uses carts and fan units
- Dynamics Sequence - Newton's 1st & 2nd Laws
- Newton's 3rd Law Sequence
- Conservation of Energy

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*Published by John Wiley & Sons, New Jersey in USA

Computer-Assisted Data Acquisition

Computer

Sensor

Interface

Vernier Software & Technology (www.vernier.com)

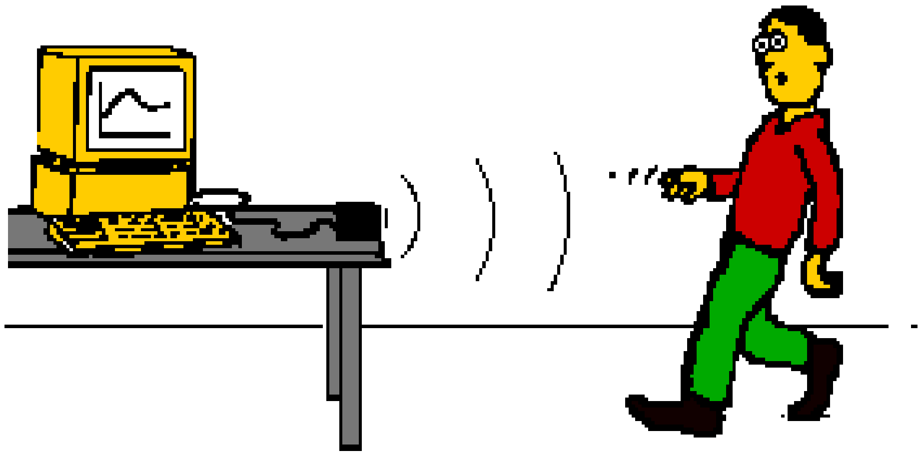
PASCO scientific (www. pasco.com)

DEMONSTRATION

MOTION DETECTOR

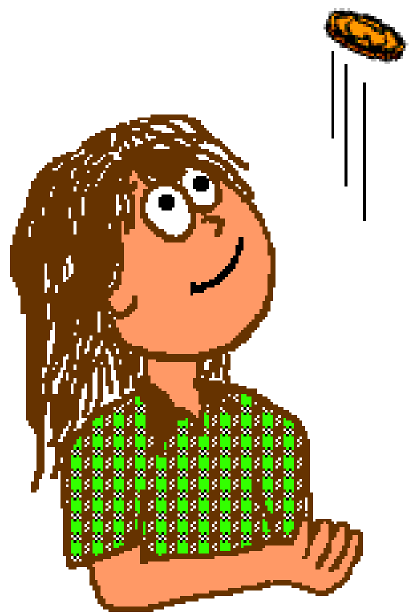
Computer Assisted Data Acquisition & Analysis Tools

- *Learn Kinematics with an ultrasonic Motion Detector first by walking and then by observing the motions of low friction carts with attached fans*



Learn Dynamics: Use ultrasonic Motion Detector data combined with force sensor data to study Newton's Laws

Free Fall of a Tossed Object Using a Motion Detector



A Mechanics ILD with Computers

Characteristics of Computer Interfacing

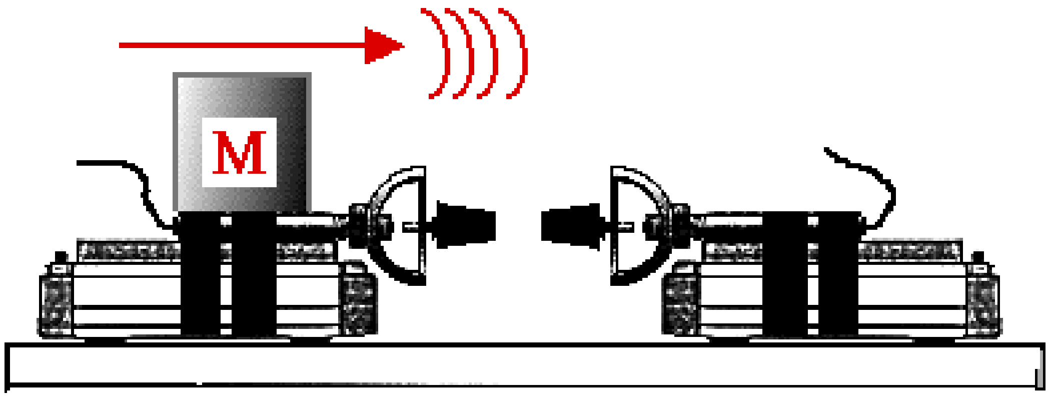
- Persistent graphs for easy comparison from different investigations
- Complete graphing, fit and statistics packages. Support of modeling through creation of new columns.
- Easy import of data into a spreadsheet for analysis
- Can be used with Windows and Macintosh Computers

What do Students Learn from Active Participation in ILDs?

Comparisons with traditional methods of lecturing and with activity-based methods such as RealTime Physics Laboratories and Workshop Physics

An Interactive Lecture Demonstration Illustrating Newton's Third Law

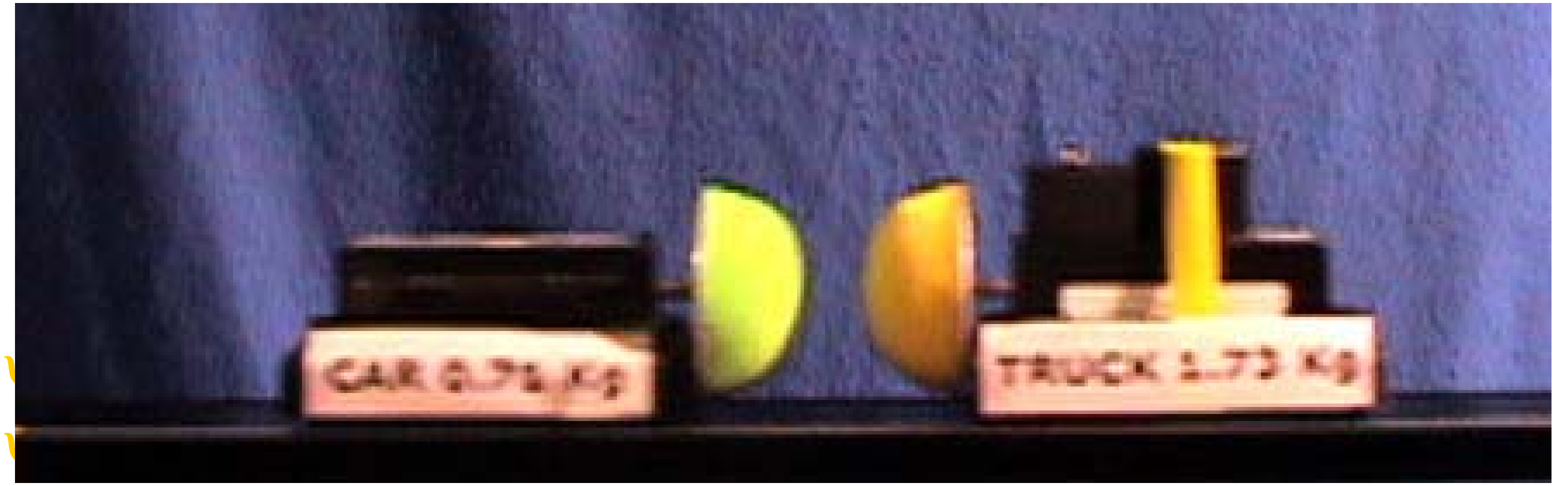
Forces of Interaction in a Collision Between Two Carts



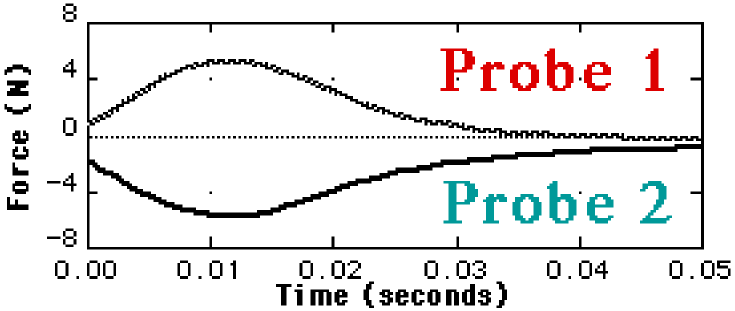
Demonstration #4: Compare the forces which the carts exert on each other during the collision.

Computer Assisted Data Acquisition & Analysis Tools (CADAA)

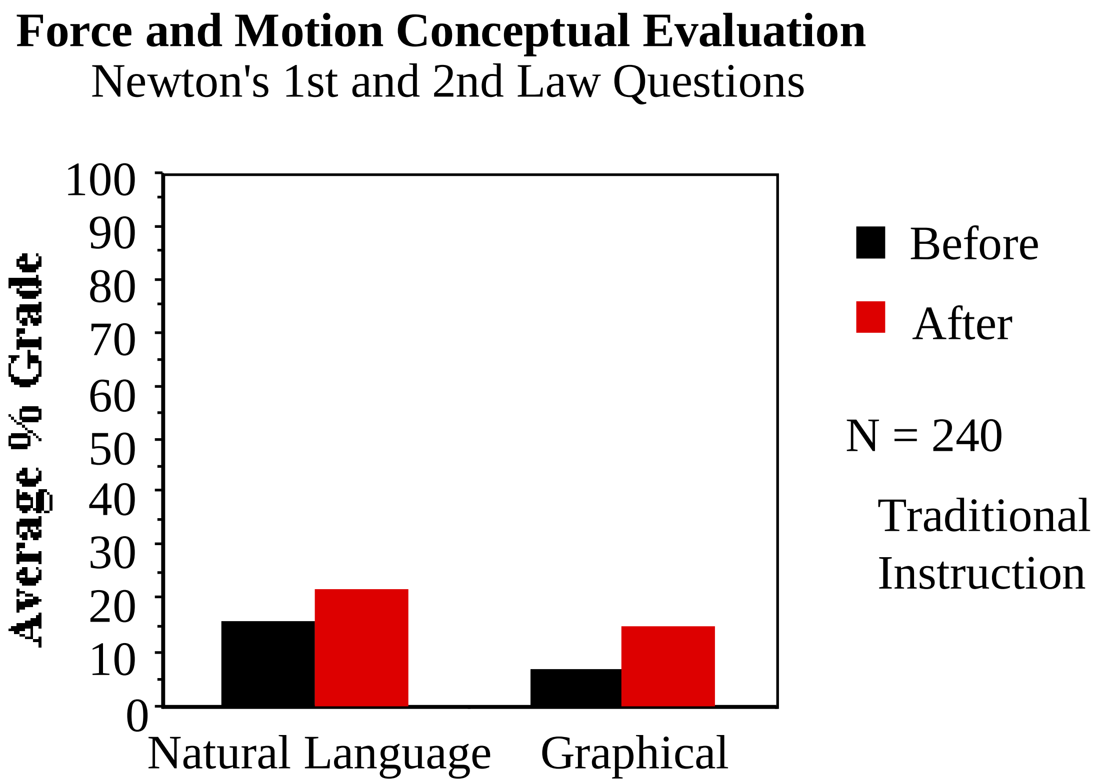
Verify Newton's Third Law using Remote Force Sensors



Impulses from Two Cart Collision

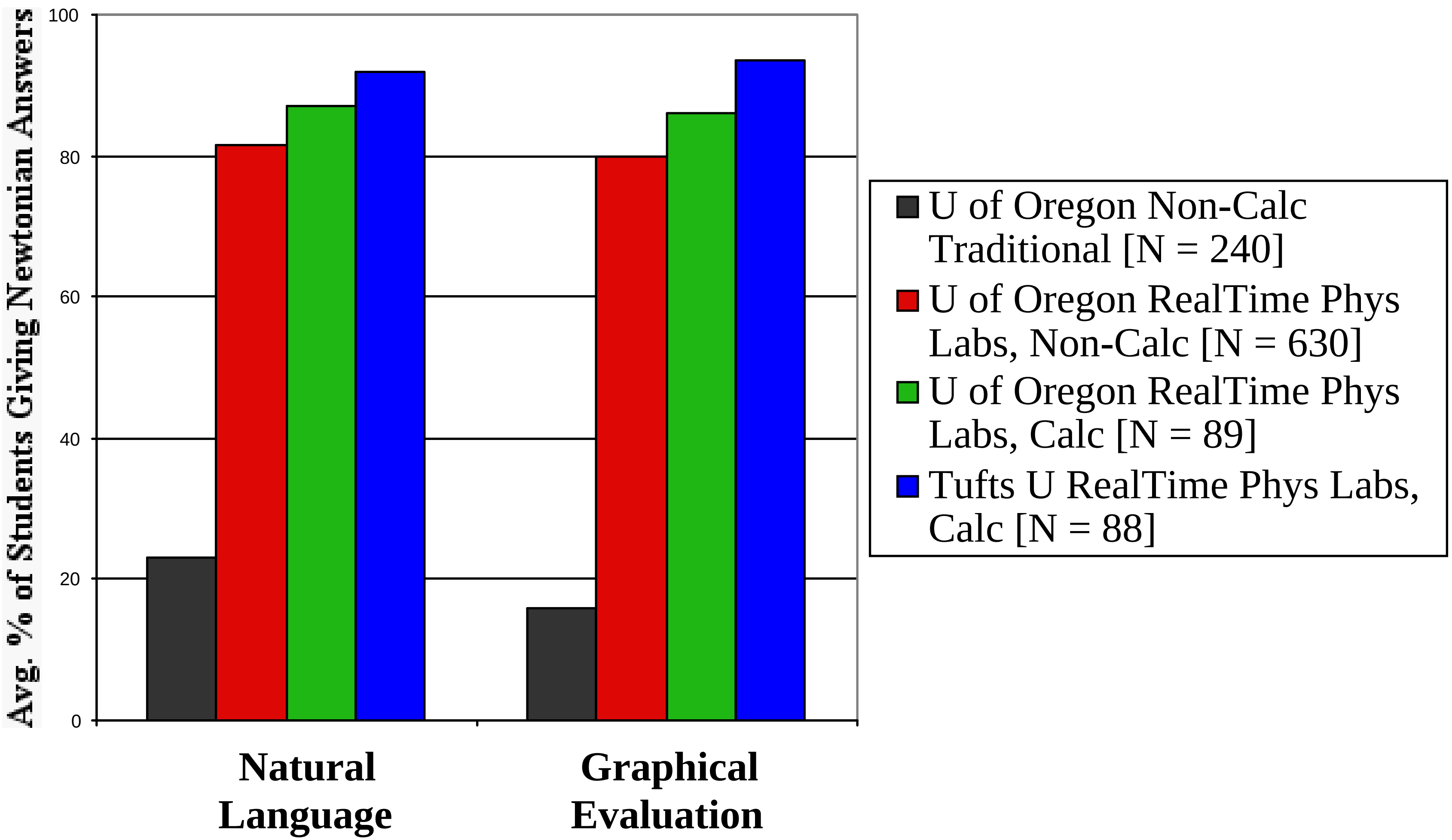


Traditional Instruction



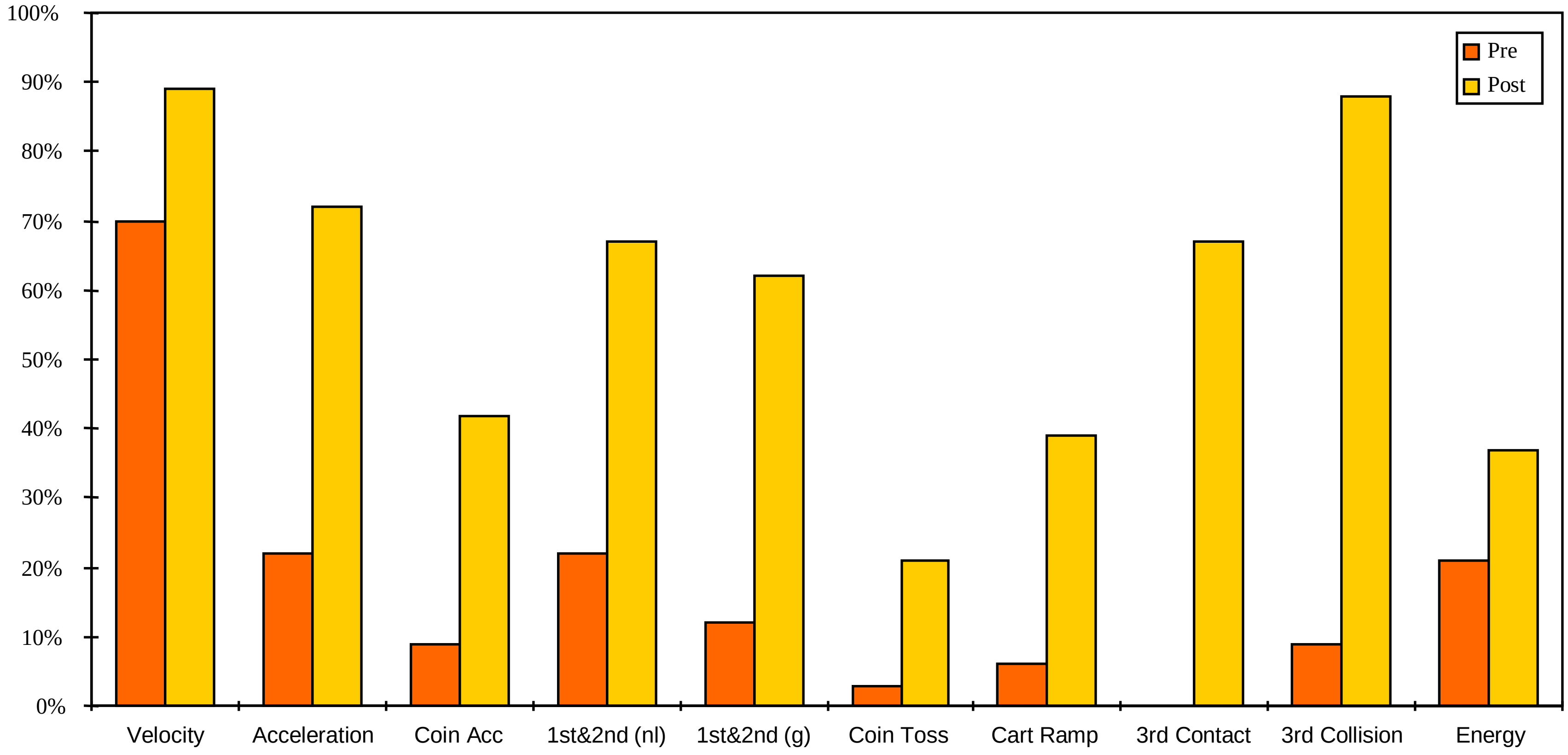
Results for Courses w/ & w/o RealTime Physics Labs

Force Motion Concept Evaluation Pre/Post



A Recent ILD HS Result

Mt. Ararat High School Spring 1998
Academic Physics with ILDs (N = 33)



Conclusions

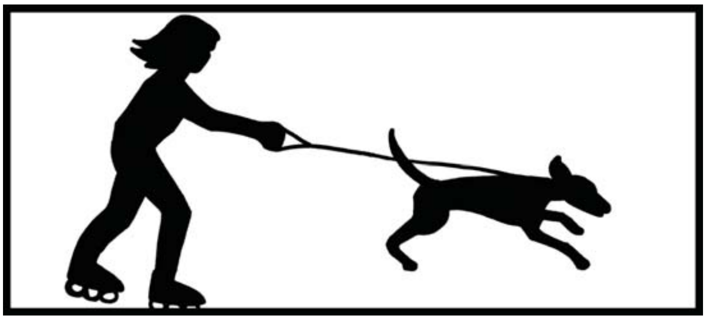
- ILDs can be used effectively in large lecture settings, small classes with only one computer, and in laboratories to review and consolidate observations
- ILDs are the most cost effective method we know of so far for teaching difficult concepts in physics that can be demonstrated with MBL tools
- Many vital physics concepts and skills can only be taught in a laboratory setting, and ILDs should not be used to replace laboratory activities

Name ____ Section ____________________Date ______________

UNIT 5: ONE-DIMENSIONAL FORCES, MASS, AND MOTION

The Apollo/Saturn V space vehicle carrying Apollo 11 astronauts Neil A. Armstrong, Michael Collins, and Edwin E. Aldrin, Jr., lifted off at 9:32 A.M. EDT on July 16, 1969. This was our nation's first manned lunar landing mission. The 36-foot-high vehicle generated a thrust of seven and one-half million pounds during liftoff. It lumbered off the launch pad very slowly at first, and then picked up speed rapidly. Its velocity may have increased at slightly more than a constant rate during the early stages of take off. This increasing acceleration was probably followed by a decreasing acceleration even if the ejected fuel created a constant thrust force on the rocket. Yet, the rocket's motion and escape from the Earth's gravitational attraction happened in accordance with Newton's Laws of motion. How is it possible for the rocket to give itself a constant thrust force and have an acceleration that is not constant? As you study the fundamental relationships between one-dimensional net force, mass, and motion in this unit, you should be able to answer this question.

UNIT 5: ONE-DIMENSIONAL FORCES, MASS, AND MOTION



If you find the study of motion difficult, reflect that it took mankind . . . over sixteen hundred years to reach a clear understanding of motion; you should hardly be impatient if it takes you several weeks.

Eric Rogers (1961)

No one must think that Newton's great creation [the three laws of motion] can be overthrown. . . . His clear and wide ideas will forever retain their significance as the foundation on which our modern conceptions of physics have been built.

Albert Einstein (1948)

OBJECTIVES

1. To devise a method for applying a constant force to an object.

2. To find a mathematical relationship between force and motion.

3. To devise a force scale to measure one, two, three, etc. units of force.

4. To understand how different one-dimensional forces acting along the same line can be combined.

5. To develop a definition of mass in terms of an object's motion under the influence of a known force.

6. To combine all of the observations and develop statements of *Newton's First and Second Laws of Motion* for one-dimensional motion with very little friction present.

5.1 OVERVIEW

So far in your study of one dimensional motion you have learned to observe and describe motion in several ways. The next step is to study the causes of motion.

The motion of an object is obviously influenced by pushes or pulls, electrical or magnetic attractions, winds, and so on. Even casual observations tell us that the way an object that is pushed or pulled moves depends on the "amount of stuff" it is made of. It's easier to push a shopping cart than a Mack truck. In physics we usually refer to a push or pull as a *force*, while we refer to the "amount of stuff" as the *mass* of an object. In this unit you will explore intuitive ideas of force and mass, and study the influence of force on motion. Finally, you will formulate two laws of motion developed by Isaac Newton in the seventeenth century.

Fig. 5.1.

Newton's Laws of motion are powerful! When forces on a system are known, Newton's Laws can be used to describe or predict its behavior.* This predictive ability is of tremendous importance to engineers who want to design bridges that don't collapse and cars that stop reliably. Also, a belief in the Laws of Motion allows scientists to deduce the nature of fundamental forces such as intergalactic forces and nuclear forces on the basis of observations of motions. As Newton stated,

> . . . the phenomena of motions [can be used] to investigate the forces of Nature, and then . . . these forces [can be used] to demonstrate other phenomena...the motions of the planets, the comets, the moon and the sea.

Note: The classical laws of motion that we will develop in this unit provide for all practical purposes "exact" descriptions of the motions of everyday objects traveling at ordinary speeds. During the early part of the twentieth century two new theories were developed—quantum theory, which describes motion in the atomic realm, and relativity, which describes objects moving extremely fast. Once you master the classical description of ordinary motions, it is exciting indeed to see how these laws are modified so that they will also describe very small objects or objects moving at extraordinary speeds (close to that of light).

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* Often when forces are known, the actual position and velocity of the system can be predicted within the limits of experimental uncertainty. However, there are some systems that exhibit chaotic behavior that can be described in terms of well-understood forces but not predicted. In Unit 15 you will study a chaotic system.

FORCE AND MOTION

5.2 MOTION FROM A CONSTANT FORCE

In your previous study of motion in this course you concentrated on describing motion rather than on understanding its causes. From your experiences, you know that force and motion are related in some way. For example, to start a bicycle moving, you have to push down on the pedals, or to start a wagon moving you have to pull on it. What kinds of forces lead to steady motion? To changes in motion?

Before you can study the relationship between force and motion, you must be able to devise a useful definition of force and develop reliable ways to measure it. Then you can investigate these relationships by applying forces of different strengths to various objects. You can begin by figuring out how to apply a constant force to a person who can slide along a smooth floor or roll along on a low friction cart. Then you can measure the motion of the person under the influence of a constant force using a computer-based laboratory system.

In order to do the activities in this section you will need some but not necessarily all of the following items to investigate the creation of a constant force:

- •1 rod
- •1 table clamp
- •1 ruler
- •1 meter stick
- •1 large rubber band, #117 (3.5” × 0.75”)
- •1 large spring scale, about 15 kg
- •1 mass pan, 1 kg
- •2 masses, 1 kg
- •3 masses, 2 kg

These items can be used to relate force and motion:

- •1 computer-data acquisition system with a motion sensor*
- •1 large plastic garbage bag
- •1 Kinesthetics cart (or large skateboard)

Recommended Group Size:	2	Interactive Demo OK?:	Y

What Is Force?

What is force and how is it measured? The word force is a very common part of everyday language. One of the major tasks in this unit is to help you move in stages from an informal understanding of the meaning of the term force as a push or pull to a more precise, quantitative definition that is useful in relating force to motion.

* Recall that a computer-data acquisition system consists of a sensor, an interface, a personal computer, and data collection software.

5.2.1. Activity: Ideas about Force

Attempt to define the word force in your own words. What are some examples of forces? How might you measure how large a given force is?

Creating a Constant Force

In order to explore the relationship between force and motion, you should try to figure out how to apply a constant force to an object. You can use any of the equipment listed for this section or any other common items you have available.

5.2.2. Activity: Applying a Constant Force

Devise a method for pulling on an object with a constant force. Explain your method and also explain why you believe that the force is constant.

Predicting Motion from a Constant Pull

Suppose you exert a fairly large constant pull on a person? We are interested in having you track the motion of a person sitting directly on a smooth level floor (or on top of a large garbage bag). Then we would like you to track the motion of a person riding on a low friction Kinesthetic Cart or skateboard. A computer based data acquisition system can be set up to track the motion with a motion sensor placed behind the person being pulled. These situations are shown in Figure 5.2.

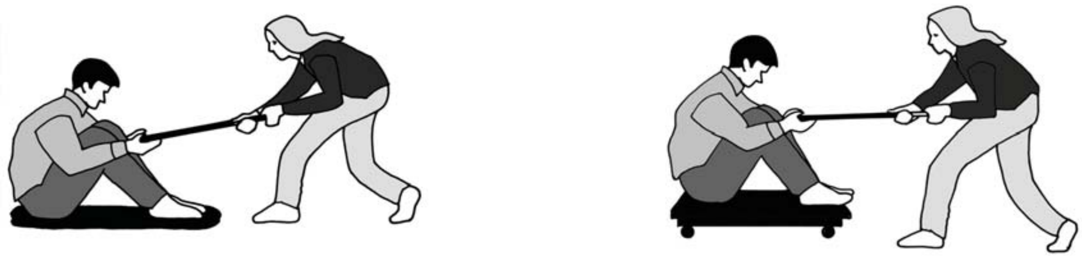
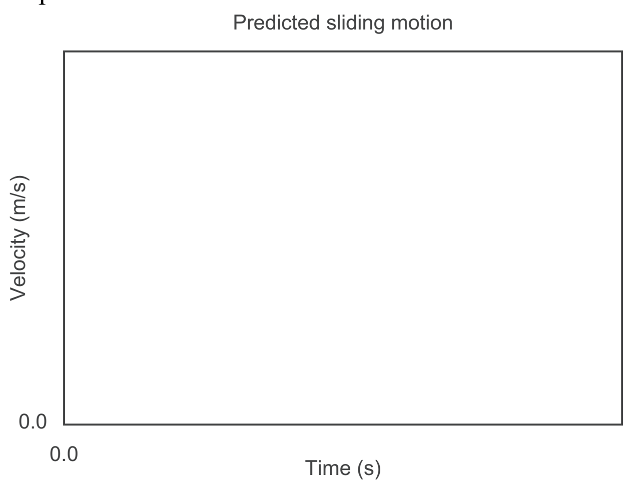


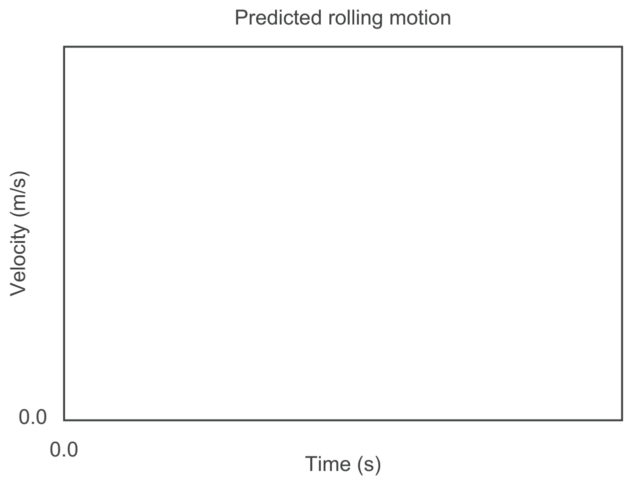
Fig. 5.2. Being pulled with a constant force under two circumstances—(a) sliding along a level floor (while sitting on a relatively smooth floor or on a plastic garbage bag) and (b) rolling along a level floor on a low-friction cart.

5.2.3. Activity: Predicting the Velocity of a Person Being Pulled with a Constant Force

a. Consider the situation in Figure 5.2a. What do you predict you might see for a velocity vs. time graph if the person starts from rest and slides along the floor while being pulled away from a motion sensor with a constant applied force? Sketch the shape of the predicted graph in the space below.



b. Consider the situation in Figure 5.2b. What do you predict you might see for a velocity vs. time graph if the person starts from rest and rolls along the floor while being pulled away from a motion sensor with a constant force? Sketch the shape of the predicted graph in the space below.



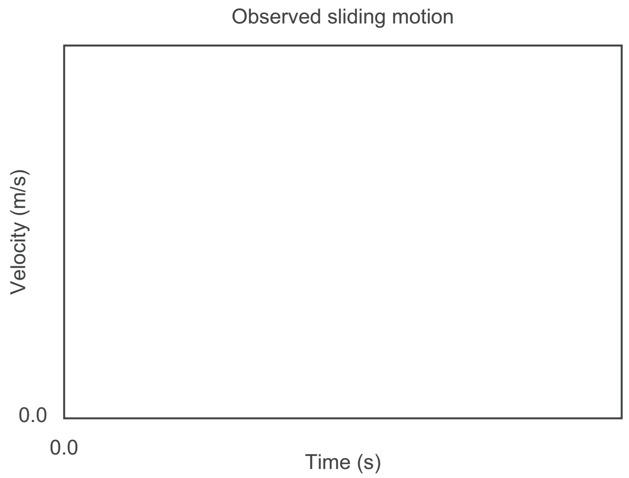
c. Explain the reasons for your predictions. If you predict that the two graphs will have the same shape, explain why. If you predict different shapes, explain why you expect the shapes to be different.

Observing Motion from a Constant Pull

You can work with the rest of the class or with one or more partners to create and record the sliding and rolling motions with a constant force using a computer-based laboratory system and motion detector. We suggest you use a large rubber band or spring scale stretched out to a constant distance to create a constant pulling force. If the person being pulled holds a meter stick, the puller can try to keep the stretch fairly constant. The person should be pulled away from the motion sensor. These motions take some practice to create. To get reliable measurements, apply enough constant force in each case to get velocities of 0.5 m/s or more for a time period of about 5 seconds.

5.2.4. Activity: Observing the Velocity of a Person Being Pulled with a Constant Force

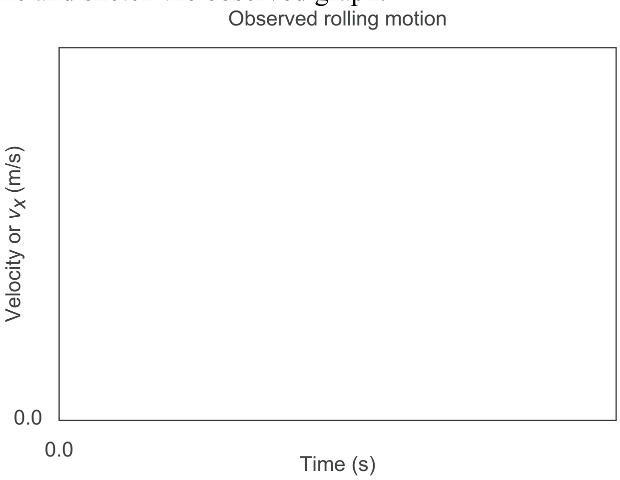
a. Create the sliding situation depicted in Figure 5.2a and observe what the velocity is as a function of time. Fill in the horizontal and vertical axis values on the following graph frame and sketch the observed graph.



b. Examine the overall shape of the graph for the sliding motion. (Ignore the smaller bumps associated with the wobbling spring or rubber band.) Is the velocity zero, constant, or changing? Is the acceleration zero, constant, or changing? Explain what characteristic of the graph shape supports your description.

c. Explain how you created the constant force. Describe the pulling method used. If you stretched the rubber band or spring, what was the amount of the stretch?

d. Create the one-dimensional rolling situation depicted in Figure 5.2b and observe what the velocity along the *x*-axis is as a function of time. Fill in the horizontal and vertical axis values on the following graph frame and sketch the observed graph.



e. Examine the overall shape of the graph for the rolling motion. (Ignore the smaller bumps associated with the wobbling spring or rubber band.) Is the velocity zero, constant, or changing? Is the acceleration zero, constant, or changing? Explain what characteristic of the graph shape supports your description.

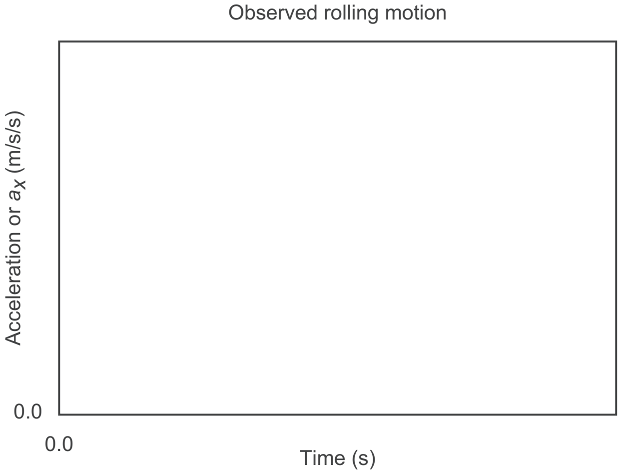
f. How did the observations you reported in a. and d. compare with your predictions?

g. State a general rule based on your observations for the relationship between a constant applied force and velocity when *friction is significant*, for example, when an object slides.

h. State a general rule based on your observations for the relationship between a constant applied force and acceleration when the friction is low.

i. Based on your observed velocity vs. time graph for the low friction rolling motion resulting from a steady pull, sketch an acceleration vs.

time graph for the time period during which the pulling force was roughly constant.



Rolling vs. Sliding Motions

You probably observed that a constant force leads to a constant velocity when an object is sliding. On the other hand, a rolling object appears to move at a constant acceleration under the influence of a constant force. This is a surprising observation to most people! The sliding motion involves a significant amount of friction while the rolling does not. In this unit, you will be working with rolling objects that have only a small amount of friction to discover Laws of Motion in the absence of friction. In Unit 6 you will return to the question of how friction can be incorporated into the laws of motion.

5.3 COMBINING EQUIVALENT FORCES

In the last section you should have discovered that a single constant force applied to a object that rolls without much friction causes it to move with a constant acceleration. What happens to the acceleration of a rolling object when the force doubles or triples? What if the force is not constant? What happens to the object's acceleration then?

Before you can proceed with further investigations of the relationship between force and motion, you need to explore reliable ways to measure arbitrary forces. *Being able to produce and combine equivalent forces will enable you to define a force scale and understand how forces of arbitrary strengths can be measured and created.*

We'd like you to work in small groups to investigate how to find equivalent forces and combine them. You will use small low-friction dynamics carts. Thus, you need to learn to work with a smaller force than the one used to pull a student riding on a Kinesthetics cart.

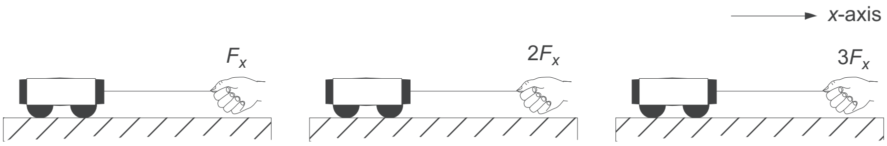


Fig. 5.3. Given a one-dimensional force F_x, how can we apply double or triple that force?

The activities in this section are not completely specified. Although the following items should be available, you might not need all of them:

- •2 table clamps
- •2 rods
- •1 ruler
- •6 rubber bands, #14
- •2 mass pans, 50 g
- •2 masses, 50 g
- •5 masses, 100 g
- •1 spring scale, 10 N

Recommended Group Size:	2	Interactive Demo OK?:	N

Equivalent Forces

A way to create double and triple forces is to combine equivalent forces. You should start this investigation by pulling a single rubber band out to some predetermined length that you choose. You can name the unit of force associated with the pull after yourself or make up another name for it.

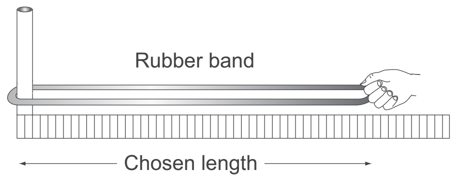


Fig. 5.4. Pulling a rubber band out to chosen length.

5.3.1. Activity: Creating Equivalent Forces

a. Pick out one of the #14 rubber bands as your standard rubber band. You may want to identify it by marking it with a pen or pencil. Now use your rubber band to define your own unit of constant force. Explain how your unit of force is created. In other words, if you were to give your rubber band to someone else, explain how they could use it to pull on something with your unit of constant force.

b. Consult with your partner(s) and decide what you want to call your unit.

c. Suppose we define an equivalent force as a force that accelerates a cart in exactly the same way that your unit of force does. Consult with your partner(s) and think of as many different techniques as possible to create an *equivalent force* using different objects than your special rubber band. Describe three or more of these techniques.

d. Now consult with your partners and think of two or more ways to test whether a proposed equivalent force is actually equivalent to your force unit.

e. Now create what you think is an equivalent force. Does the "equivalent" force pass the tests you have devised in part d. for equivalency? Explain.

Evaluating Alternatives for Testing Equivalent Forces

Sometimes when there are alternative ways to accomplish a goal some seem better than others. You should discuss your ideas and findings with your classmates and then choose what you think is the best technique for creating a force that is equivalent to your unit in terms of its ability to accelerate a cart in the same way that your force did.

5.3.2. Activity: Equivalent Force Techniques

a. Are there any other tests for equivalency suggested by classmates that you and your partners didn't think of? If so, list them below.

b. Which do you think is the most scientifically sound test for equivalency? Which of the techniques do you prefer to use to create an equivalent force? Why do you prefer it? How do you know it is valid?

Combining Equivalent Forces

Since the goal in this section is to learn produce and measure forces of arbitrary strengths, you can start by combining equivalent forces to create a force scale. Let's assign an *x*-axis that is parallel to the line of motion you are studying. You can then denote your basic unit of force as F_x.

5.3.3. Activity: Creating F_x, $2F_x$, $3F_x$, . . .

Describe how you could use a batch of essentially identical rubber bands to create forces that have double and triple the strength of your initial force unit.

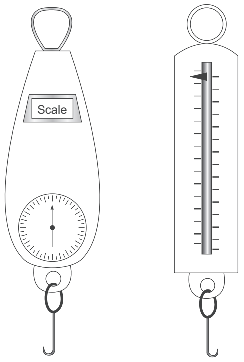


Fig. 5.5. Two types of spring scales used to measure forces in Newtons.

5.4 USING STANDARD UNITS TO MEASURE FORCE

So far you have been measuring forces in your own units using procedures that you and your partners have defined. If you measure forces and want to have scientists in another location understand your results, it would be convenient if everyone used the same force unit. The accepted standard unit for force is the *Newton*. The Newton is defined as the force that is needed to give a 1 kilogram mass an acceleration in which the velocity of an object increases by 1 meter per second each second. We're getting ahead of ourselves because we haven't defined the kilogram as a unit of mass yet. We will soon.

A scientifically rigorous way to measure a force of 1.0 newtons is to take a 1.0-kg object that can move without friction and apply just the right force to it to get an acceleration of 1.0 m/s/s. That force would, by definition, be one newton—at least to two significant figures. But it is a pain to have to go to all that trouble, and you can use a standard device for measuring force in newtons instead.

The most common device for measuring forces in newtons consists of a spring with a scale attached to it that is marked off in newtons. In theory, someone already figured out how much the spring has to stretch to get a 1.0 kilogram mass moving with an acceleration of 1.0 m/s/s and combined forces to define the appropriate scale.

Another less common but very useful way to measure force is to use an electronic force sensor attached to a computer-data acquisition system that has been *calibrated* to read in newtons.

In the activities in this section, you will measure forces in newtons with both a spring scale and an electronic force sensor using the following equipment:

- 1 ruler
- 6 rubber bands, #14
- 1 spring scale, 10 N
- 1 computer-based laboratory system
- 1 force sensor
- 1 motion software

Recommended Group Size:	2	Interactive Demo OK?:	N

Measuring Force in Newtons with a Spring Scale

You should devise a way to use rubber bands to show that the forces indicated on a spring scale in Newtons are proportional to your rubber band units.

5.4.1. Activity: Converting Your Units to Newtons

a. Devise a way to show that the forces indicated by a spring scale in Newtons are proportional to your rubber-band units. Explain what you did and show your data and graph in the space below.

b. Find a conversion factor between your personal rubber-band units and Newtons. Explain how you determined the factor and show any calculations in the space below.

Calibration of an Electronic Force Sensor

It is very useful to be able to read forces in Newtons using an electronic force sensor. Some types of electronic force sensors require calibration before they can record forces in Newtons. In general, calibration involves finding a relationship you or a computer program can use to convert readings on the measuring instrument to the quantity you want to measure. Procedures for force sensor calibration are either built into the motion software or require a mechanical adjustment in the sensor. To calibrate your force sensor using the spring scale as a standard:

1. Set up your computer-data acquisition system with a force sensor, motion detector, and interface.
2. Calibrate the force sensor. (You should refer to your sensor manual or software help routine for calibration instructions.)

5.4.2. Activity: Calibrating the Force Sensor in Newtons Using a Spring Scale

a. Use a 5.0 N force as indicated on the spring scale to calibrate your force sensor. What do you think are the major sources of uncertainty in your procedure?

b. Check the accuracy of your calibration, pull on the force sensor with a spring scale that reads 3.0 N of force. Is your calibration accurate? If not, repeat part a.

c. Select a force-time graph. Push and pull on the force sensor and look at the reading on your graph. Is one Newton a very large force? Explain.

d. What is the largest pulling (or positive) force you can measure before the force-time graph flattens out, indicating that the force sensor-computer system has been driven beyond its limits?

RELATING ACCELERATION AND FORCE

5.5 MEASURING ACCELERATION AS A FUNCTION OF FORCE

You have already determined that, for a situation in which friction is small, a constant force on an object causes it to accelerate at a constant rate. Now that you have a more thorough understanding of how forces can be defined and measured, you are ready to investigate the relationship between the magnitude and direction of the applied force and magnitude and direction of the resulting acceleration for different forces on a moment-by-moment basis.

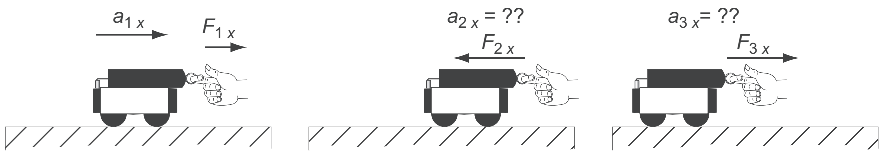


Fig. 5.6. How does the measured acceleration along an *x*-axis of a low-friction cart change when the applied force on it is changed?

5.5.1. Activity: Predicting Acceleration or Velocity vs. Force

a. Suppose you push and pull on a force sensor attached firmly to a low-friction cart and obtain a graph of force vs. time like that shown below. Do you expect the velocity vs. time or the acceleration vs. time graph to have the same shape as the force vs. time graph does? Explain the reason for your prediction in light of observations you have already made when applying a constant force to a person on a cart.

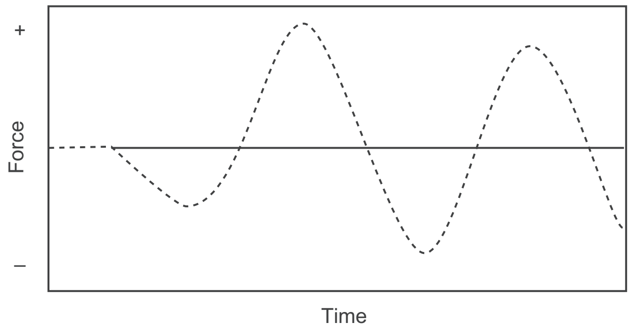
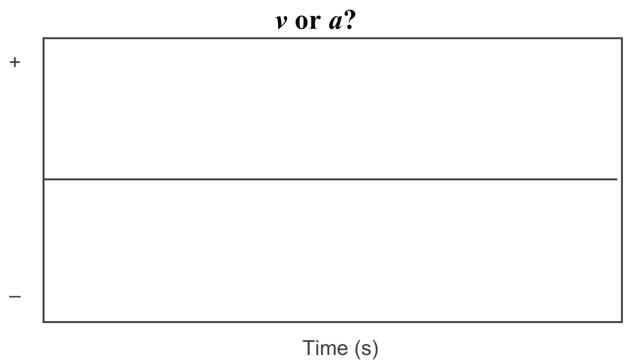


Fig. 5.7.

b. Consider the previous graph that shows sample force vs. time data. Sketch the predicted shape of the graph of corresponding velocity vs. time or acceleration vs. time. Please label the graph's vertical axis.



In order to investigate how acceleration and force are related, you will push and pull on a force sensor that is attached to a cart and record the motion of the cart. You will need:

- •1 small low-friction dynamics cart
- •2 masses, 500 g (to add mass to the cart)
- •1 smooth ramp or level surface 1–3 meters long
- •1 computer-based data acquisition system
- •1 ultrasonic motion sensor
- •1 force sensor (with a hook on its sensitive end)
- •1 adapter bracket (to attach a force sensor to the cart)
- •1 spring scale, 10 N (to calibrate the force sensor)

Recommended Group Size:	2	Interactive Demo OK?:	Y

To do the next activity you will push and pull on a cart while measuring both the force and motion continuously. You can start by attaching a force sensor (with a hook on its end) firmly to a cart. Then you should add about 1.0 kg of mass to the cart and place it on a smooth level track or surface.

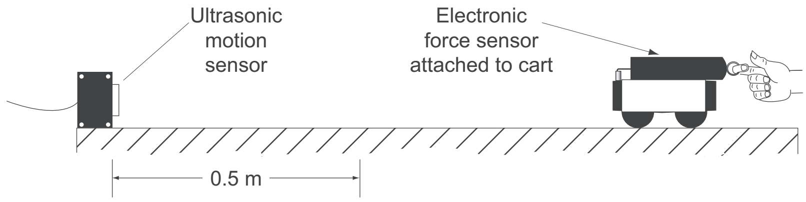


Fig. 5.8. Setup showing a motion sensor tracking the acceleration of a cart rolling on a level track as a force sensor detects the pushes and pulls on it. As usual, the cart must be at least 0.5 m away from the motion detector at all times.

If needed, calibrate the force sensor to read forces between 0 and 5 Newtons. Set up the motion software to display two graphs: Force vs. time and acceleration vs. time for about 5 seconds.

5.5.2. Activity: Measuring Acceleration vs. Force

a. Zero the force sensor and record data as you grip the hook on the end of the force sensor firmly to push and pull the cart back and forth on the track *smoothly*. Repeat this process until you have smooth reliable data. Then sketch the force and acceleration graphs. **Note:** If your acceleration graph seems rough and has spikes on it, you should set the averaging for the velocity and acceleration data at something between 5 and 15 points so that small uncertainties in data do not appear on the acceleration graphs.

b. You should have observed that the force and acceleration graphs do indeed have the same shape. Is this what you predicted in Activity 5.5.1?

Are Force and Acceleration Proportional to Each Other?

The fact that the graphs of force and the resulting acceleration caused by it have the same general shape suggests that force and acceleration might be proportional to each other. Recall that if two variables are proportional, a graph of one variable as a function of the other is a straight line passing through the origin, and that the equation relating them would have the form

$$F_x = ma_x \quad (5.1)$$

where F_x represents the force acting, a_x represents the acceleration, and m represents the slope of the graph and is the constant of proportionality. Since you have a computer-generated table of values of a_x and F_x for a whole series of times, you can use the data you just gathered to test for proportionality between a_x and F_x.

5.5.3. Activity: Finding the Mathematical Relationship Between Acceleration and Force

a. Use the analysis feature of your motion software or display a data table to obtain about five sets of a_x and F_x values. Two significant figures will be fine. **Hint:** Find the corresponding values of F_x when a_x is the most negative, approximately zero, and the most positive. Then find a couple of sets of a_x and F_x values when a_x is between the most negative and zero and between the most positive and zero.

	a_x (m/s/s)	F_x(N)
1		
2		
3		
4		
5		

b. Create a graph of F_x vs. a_x with properly labeled axes including units and affix it on the following page. **Note:** It is conventional to plot the independent variable on the x-axis and the dependent variable on the y-axis. Using this convention, you should graph a_x as a function of F_x *because* F_x is the independent variable that you can change at will as you push or pull on the cart. However, it is more convenient in later activities if you graph F_x as a function of a_x instead.

(Affix your graph here.)

c. Graphs of experimentally determined relationships are seldom perfect since there is usually some scatter due to uncertainties. Taking this fact into account, does the relationship between F_x and a_x appear to be a proportional relationship? Why or why not?

d. If the relationship is proportional, what is the constant of proportionality (i.e., the slope of the graph)? Explain how you determined the slope and include units for it. (Fitting, mathematical modeling, drawing a best slope by hand and estimating its value, etc.)

e. Write the general equation that relates F_x and a_x in terms of the symbol, m, which represents the slope of the graph.

You have just discovered a one-dimensional law of proportionality between an applied force and acceleration for the situation in which there is almost no friction. This is almost, but not quite, one of Newton's famous laws of motion. Before you can enrich the law of proportionality, you will need to explore how the properties of the object being accelerated affect the proportionality constant. In addition, you need to learn about what happens when more than one force acts on an object at the same time.

5.6 NET FORCE: ADDING AND SUBTRACTING FORCES

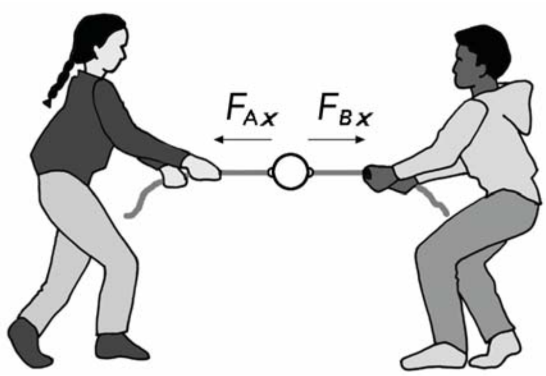


Fig. 5.9. What is the net effect of forces acting in opposite directions at the same time?

In this section we will consider what happens when more than one force acts on an object along the same line at the same time. We have not yet thought formally about how forces combine. In doing so, it is useful to treat forces as mathematical entities. Let's postulate that one-dimensional forces behave mathematically like vector components.

A one-dimensional vector component is a mathematical entity that has both a direction along an axis and a magnitude. If we choose an x-axis to lie along the same line as the one-dimensional forces we are considering, then a vector component can have a direction along the positive x-axis or a direction along the negative x-axis. The magnitude or strength of a one-dimensional force can be represented by a single number, while the direction of a force can be expressed in terms of a plus or minus sign in front of the number representing the strength of the force. One-dimensional vector components can be represented as the product of their magnitude and direction along an x-axis as shown below.

1D forces represented as vector components having the same direction

$F_{Ax} = +5.5$ N and $F_{Bx} = +3.4$ N

or $F_{Ax} = -5.5$ N and $F_{Bx} = -3.4$ N

1D forces represented as vector components acting in opposite directions

$F_{Ax} = +2.3$ N and $F_{Bx} = -7.7$ N

or $F_{Ax} = -2.3$ N and $F_{Bx} = +7.7$ N

Note: When a vector component is used to represent a physical quantity, we always include the units. In this case, the newton or N is used for force.

You can do some simple observations to determine whether or not one-dimensional forces behave like vectors. To do this you will need:

•3 identical spring scales, 10 N
•1 small low-friction cart

Recommended Group Size:	2	Interactive Demo OK?:	N

5.6.1. Activity: Do 1D Forces Behave Like Vectors?

a. Describe what happens when a spring scale is hooked to one end of a resting cart and extended in a horizontal direction so that its force is equal to 2.0 N in magnitude. The force points along the positive *x*-axis. Does the cart move? If so, in what direction? This should be a casual observation—no need to take any data.

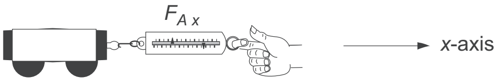


Fig. 5.10.

b. Draw an arrow that represents a scale drawing of the magnitude and direction of the force you are applying. Let one centimeter of arrow length represent each Newton of force. Label the arrow with an F_{Ax} and indicate whether F_{Ax} = +2.0 N or –2.0 N.

c. Observe what kind of motion results when two spring scales are hooked to opposite ends of the cart and extended in a horizontal direction so that each of their forces is equal to 2.0 N in magnitude but opposite in direction. Does the cart move? If so, how. What is the combined or net force on the cart? Indicate whether F_{Bx} = +2.0 N or –2.0 N.

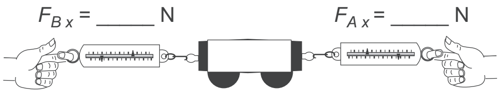


Fig. 5.11.

d. Draw arrows that represent a scale drawing of the magnitudes and directions of the forces you are applying. Let one centimeter of arrow length represent each Newton of force. Label each arrow appropriately with an F_{Ax} or an F_{Bx}.

e. What kind of motion results when two identical springs are displaced by the same amount in the same direction (e.g., when each spring is displaced to give 1.0 N of force)? How does this compare to the force of one spring displaced by twice that amount (e.g., so that it can apply 2.0 N of force)? Describe what you did and the outcome.

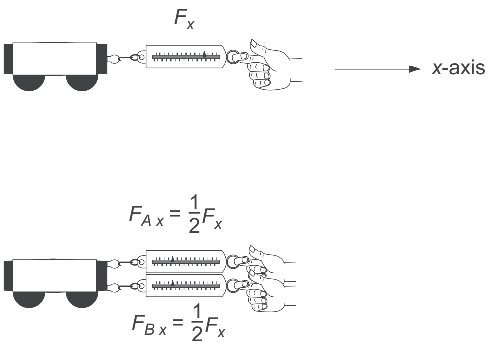


Fig. 5.12.

f. Draw arrows that represents a scale drawing of the magnitudes and directions of F_{Ax}, F_{Bx}, and F_x.

g. In the space below, fill in the number and unit that represents each vector component.

F_x = _________ F_{Ax} = _________ F_{Bx} =_________

h. Do one-dimensional forces seem to behave like one-dimensional vector components? Why or why not?

If one-dimensional forces can be described as vector components, then we can denote combinations of vectors such as those in Activity 5.6.1c and e by the equation

$$F_x^{net} = \sum F_x = F_{Ax} + F_{Bx}$$

where F_x^{net} represents the sum of the vector component of two or more one-dimensional forces acting along a chosen x-axis. Some textbooks refer to a net force as a combined or total force. Other text authors write about the resultant force. Combined, total, resultant, or *net* force all refer to the same thing.

5.6.2. Activity: Calculating a Net Force

a. Let's choose an x-axis that is positive to the right and negative to the left. Suppose a force C has a magnitude of 1.5 N and acts toward the left on a cart and a second force D has a magnitude of 0.9 N and acts toward the right on a cart. Express each force in vector component notation. **Hint:** Don't forget to include the proper sign, the magnitude, and the units in each case.

b. Calculate the net force F_x^{net} using proper vector component notation and explain how you calculated it.

You should note that one-dimensional velocities and accelerations can also be described by vector components because they too have magnitudes *and* directions.

One of your goals is to continue to refine your understanding of the relationship between one-dimensional forces and motion. You just investigated how one-dimensional forces combine like vector components in terms of their ability to cause acceleration. *We can now state that acceleration caused by several forces acting in one dimension on an object that experiences very little friction is proportional to the net force on the object.*

5.7 WHAT HAPPENS WHEN THE NET FORCE IS ZERO?

Let's consider an important special situation in more detail—the situation in which the net force acting in one dimension on an object in the absence of significant friction is zero. Start by summarizing what you already know.

5.7.1. Activity: Facts About Zero Net Force and Motion

a. Suppose we apply a force in the positive direction along an *x*-axis (toward the right) on a small low-friction cart and another force acting along the same line of equal magnitude in the negative direction on the cart (toward the left). If the law of proportionality between force and acceleration holds, what will the acceleration vector component, a_x, of the cart be? **Hint:** Don't forget to include units!

a_x = ____________________

b. What is the acceleration component of a cart that is:

1. at rest?

a_x = ____________________

2. moving with a constant negative velocity along an *x*-axis?

a_x = ____________________

3. moving with a constant positive velocity along an *x*-axis?

a_x = ____________________

c. Suppose an object is moving with a constant velocity and experiences no net applied forces and no friction. Is its continued motion with a constant velocity compatible with the law of proportionality between net force and acceleration or does it violate that law?

d. What can you say about the net force component on the cart mentioned in part b for each of the three cases?

We would like you to investigate whether or not a low-friction cart that has a zero net force on it can move at a constant velocity. To undertake this investigation we suggest that you apply forces in opposite directions with the same strength on a cart using two hanging weights as shown in Figure 5.13.

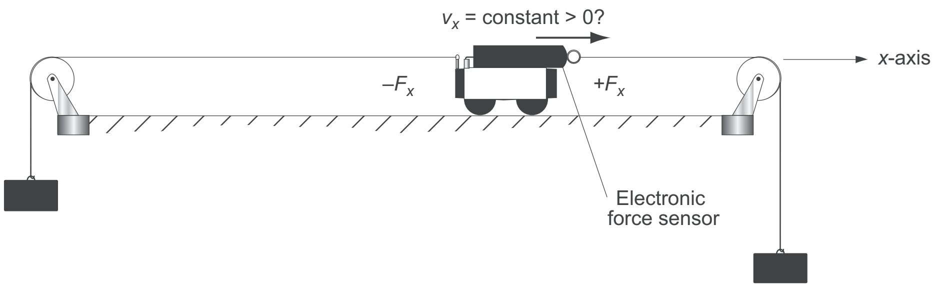


Fig. 5.13. Setup showing a low-friction cart rolling on a level track as two hanging weights combine to exert zero net force on the cart.

We recommend that this activity be done as a demonstration with the entire class participating. The items needed for the demonstration include:

- •1 high table
- •1 smooth ramp or level surface 2 meters long
- •1 small low friction dynamics cart
- •2 lengths of string, 2 m
- •2 low friction pulleys
- •2 mass pans, 1 kg
- •1 set of slotted masses (5 g to 100 g)
- •1 computer-based laboratory system
- •1 force sensor
- •1 motion software

Recommended Group Size:	All	Interactive Demo OK?:	Y

Before making the observations you should level the track and balance the masses on either side with the smaller slotted masses so that, if the cart is stationary at first, it stays at rest and doesn't accelerate in either direction. An electronic force sensor should be firmly attached to the cart to help verify that the pulling forces on the cart don't change as the cart moves to the right or the left during the observations.

5.7.2. Activity: Motion with No Net Force

a. Suppose a cart receives a brief push that starts it moving in one direction or another. If there is no net force on it after the push, what do you predict its motion will be like? Try to imagine that there is no friction acting on the cart. Explain the reasons for your prediction.

b. Is your prediction compatible with the proportional relationship between force and acceleration that you discovered previously?

c. Observe what happens after the cart is pushed in one direction and allowed to move freely with no net force. Describe your observation. Is the velocity of the cart constant or decreasing? Does the cart seem to be accelerating?

d. The observation you just made should enable you to state Newton's First Law of Motion. *Please finish the statement in a way that is compatible with your actual observation.*

NEWTON'S FIRST LAW: If an object moving at a constant velocity, $\vec{v}$, without friction experiences no net force, it will . . .

Remarks About Newton's First Law

Newton's First Law is of deep significance because it allows an observer who is moving at a constant velocity with respect to another observer to discover the same laws of motion. For example, suppose you observe that the small cart is at rest in the laboratory and your partner makes the same observation while moving away from you at a constant velocity on a Kinesthetic cart. Your partner will see the small cart moving away with a constant velocity. But both of you can agree that the cart is not accelerating and therefore is experiencing no net force!

RELATING FORCE, MASS, AND ACCELERATION

5.8 DEFINING AND MEASURING MASS

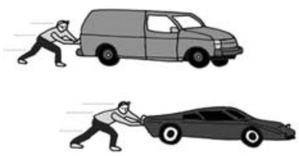


Fig. 5.14. Would you rather push a sports car or a larger van?

A good friend calls you in a panic. His battery is dead and he needs to have you come outside and help push his car to get it started. He needs to have you get it moving at about 12 mph so he can throw it in gear and turn over the engine. You blithely answer sure, you'll be right out. Then you remember that your friend owns two vehicles—a large delivery van and a smaller sports car. Since you can exert only so much force and you're feeling like an 80 lb weakling, you hope that your friend is driving the easiest of the two cars to push.

5.8.1. Activity: Causing a Car to Accelerate

a. Which vehicle do you think would be easier to accelerate from rest to a speed of 12 mph with a given force—a small car or a large van? Explain.

b. What characteristic of an object seems to determine how much force is needed to accelerate it?

Somehow the magnitude of force required to cause an object to accelerate by a given amount is related to the "amount of stuff" being accelerated. It is pretty obvious to most people that if there is more stuff, then more force will be required to accelerate it. But suppose we double the amount of stuff. Will that mean that twice the force is needed to accelerate double the stuff?

The stuff we are referring to is what scientists usually call mass. Let's take some time to consider the question of what mass is and how we might measure it.

What Is Mass?

Philosophers of science are known to have great debates about the definition of mass. If we assume that mass refers somehow to "amount of stuff," then we can develop an operational definition of mass for matter that is made up of particles that appear to be identical. We can assume that mass adds up and that two identical particles when combined have twice the mass of one particle; three particles have three times the mass; and so on. But suppose we have two objects that have different shapes and are made of different stuff, such as a small lead pellet and a silver coin. How can we tell if these two entities have the same mass?

5.8.2. Activity: Ideas About Mass and Its Measurement

a. Attempt to define *mass* in your own words without using the word "stuff."

b. How many different ways can you think of to determine whether a lead pellet and a silver coin have the same mass?

c. Suppose you find that the lead pellet and the silver coin seem to have the same mass. How could you create "stuff" that has twice the mass of either of the original objects?

Using a Mass Balance

One time-honored way that people have used to compare the mass of two objects is to put them on a balance. If they happen to balance each other, we say that the "force of gravity" or the force of attraction exerted on them by the earth is the same, so they must have the same mass.

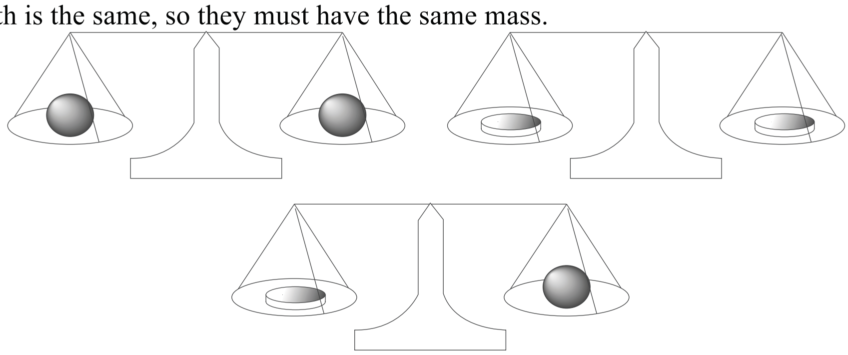


Fig. 5.15. A common method of determining mass that assumes two objects have the same mass if they experience the same gravitational force.

Actually, if we balance gravitational forces as the method of determining mass, we are only determining a *passive gravitational mass*. A passive gravitational mass is proportional to the force of attraction exerted by the earth on the mass. How can we use a balance to measure the mass of any object relative to a standard mass?

Let's do a thought experiment. Suppose Maya makes the outrageous claim that her dove has the same mass as 79 silver quarters and is worth her weight in quarters. Can you doublecheck her claim using a balance, a quarter as the "standard mass," and a pile of sand? **Hint:** This is an exercise in basic logic.

5.8.3. Activity: Using a Balance to Measure an Arbitrary Mass

Explain how you might measure the passive gravitational mass of Maya's dove using the balance, sand, and standard coin.

Other Ways to Measure Passive Gravitational Mass

In most modern laboratories, spring scales and electronic scales that are easier to use now replace the old-fashioned balance. As the earth attracts a mass hanging from a spring, the spring will stretch. A mass placed on the platform of an electronic scale will cause it to depress. The amount of depression can be detected electronically.

5.9 HOW MASS AFFECTS MOTION

You have already verified a law of proportionality between one-dimensional force and acceleration when little friction is present. This law can be expressed in the form

$$F_x^{net} = ma_x \qquad (5.1)$$

where F_x^{net} is the net force exerted on an object, m is the slope of the graph of F_x^{net} vs. a_x or the constant of proportionality, and a_x is the acceleration along the line that the net force acts. We know that this constant of proportionality, m, which represents a resistance of an object to acceleration, doesn't necessarily have anything to do with gravity.

Since it requires more force to accelerate more gravitational mass our intuition tells us that the proportionality constant ought to be related to passive gravitational mass. Is it possible that the passive gravitational mass of an object is the same as the proportionality constant, or slope, relating F_x and a_x? In other words, *will accelerating twice as much passive gravitational mass by the same amount take twice as much force*? This is the question we posed in Section 5.7.

To answer this question you should investigate the forces and accelerations that arise when you push and pull on rolling carts having different passive gravitational masses. This investigation is basically an extension of the one you undertook in Section 5.5. For the next activity you will need:

- 1 balance
- 2 pieces of string (to use with the balance)
- 1 electronic scale
- 1 small low-friction dynamics cart
- 1 set of assorted masses (1 g, 2 g, 5 g, 10 g, 20 g, 50 g, 100 g, 200 g)
- 1 smooth ramp or level surface 1–3 meters long
- 1 computer-based laboratory system
- 1 motion software
- 1 ultrasonic motion sensor
- 1 force sensor*
- 1 adapter bracket (to attach a force sensor to the cart)
- 1 spring scale, 10 N (to calibrate the force sensor if needed)

Recommended Group Size:	2	Interactive Demo OK?:	Y

Before doing the activity, attach a force sensor with a hook on its end firmly to the cart. Place the cart on a smooth level track or surface.

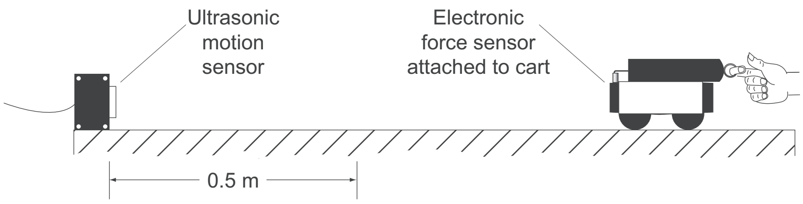


Fig. 5.17. Setup showing a motion detector tracking the acceleration of a cart rolling on a level track as a force sensor detects the pushes and pulls on it. As usual, the cart must be at least 0.5 m away from the motion detector at all times.

When you did a similar observation in Section 5.5 you collected data for force vs. time and acceleration vs. time to see the shapes of the graphs. Since you were also interested in the relationship between force and acceleration you plotted a graph of this relationship using some sample data and found the slope of the graph. This time you should set up the motion software to display three graphs:

1. force vs. time
2. acceleration vs. time
3. force vs. acceleration

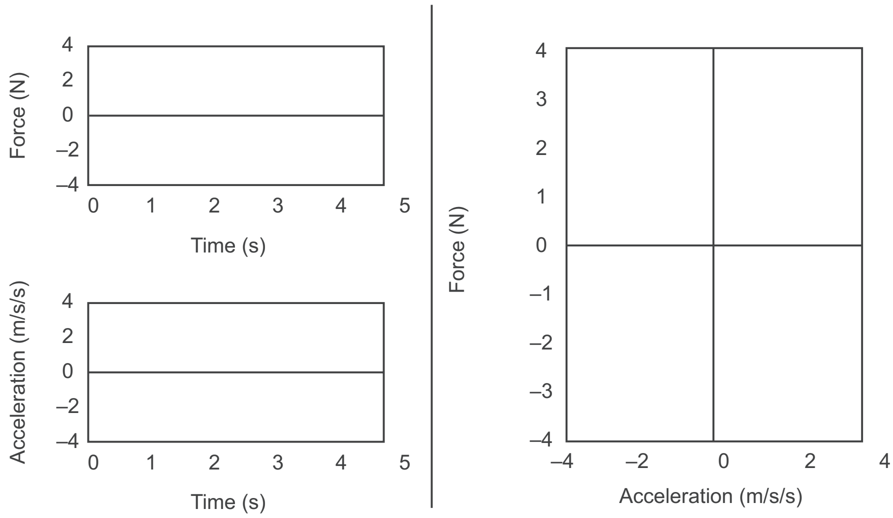
If needed, calibrate the force sensor to read forces between -5 and +5 N.

5.9.1. Activity: Measuring Acceleration vs. Force

a. Zero the force sensor (if needed) and record data as you grip the force sensor hook firmly to push and pull the cart back and forth on the track smoothly. Sketch the force and acceleration graphs you

* Because of its linearity, low noise, and built-in calibration, we recommend that the PASCO Force Sensor (models CI-6537 or CI-6618) be used for this activity.

observed. **Note:** If your acceleration graph seems rough and has spikes on it, (1) you should set the averaging for the velocity and acceleration data at something between 5 and 15 points so that small uncertainties in data do not appear on the acceleration graphs, and (2) you should try to push and pull with a maximum force of about 4 N.



b. Use the linear fitting feature in the motion software to find the slope of the graph of force vs. acceleration. What is the value of the slope and its standard error? Be sure to include units.

Slope: $m =$

Standard Deviation from the Mean: SDM=

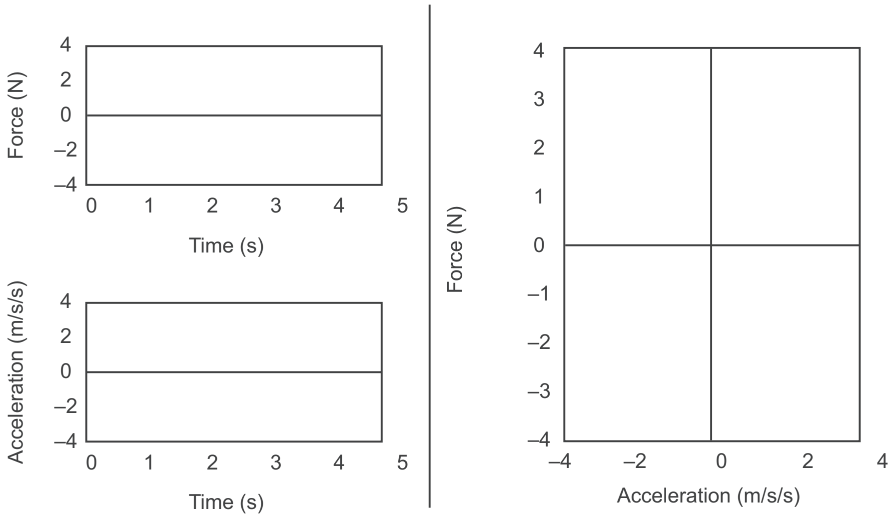
Doubling the Gravitational Mass

Suppose you put enough mass on the cart to double its mass. How much more force must you exert to push and pull on the more massive cart so that its acceleration vs. time graph looks about the same as the graph you obtained in Activity 5.9.1a?

5.9.2. Activity: Acceleration vs. Force for Twice the Mass

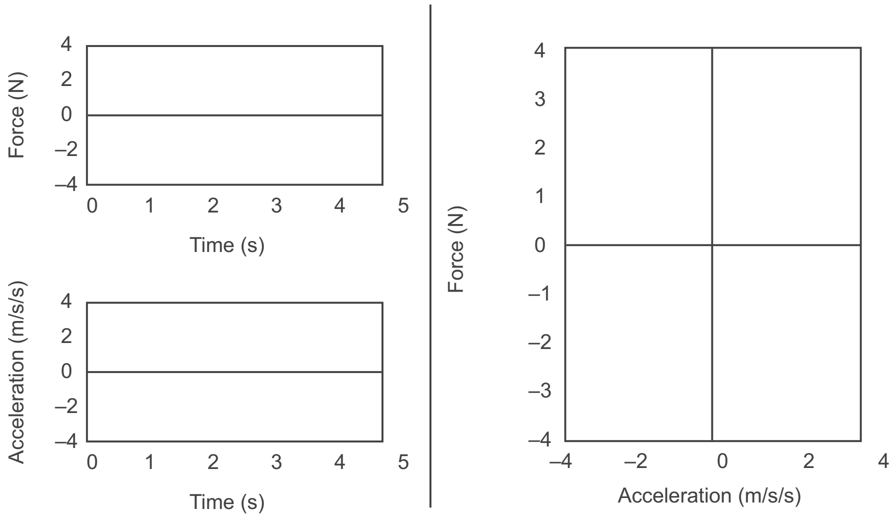
a. Suppose you were able to push and pull on a cart having twice the mass as before so that the acceleration vs. time is approximately the same. Do you think the slope of the F vs. a graph will increase, decrease, or remain the same? Explain.

b. Sketch the predicted shapes of all three graphs.



c. Use the balance to compare the combined mass of the cart, force sensor, and sensor holder to that of a collection of assorted masses. Include enough assorted masses to just balance the gravitational mass of the cart-sensor system.

Place this combination of masses on the cart so that the cart with added masses, force sensor, and sensor holder now have twice the gravitational mass as before. Zero the force sensor (if needed) and record data as you grip the force sensor hook firmly to push and pull the cart back and forth on the track *smoothly*. Sketch the force and acceleration graphs you observed.



d. Using the linear fit feature in the motion software, indicate the value of the slope and the standard error of the force vs. acceleration graph. Include units for the slope.

Slope: $m =$

Standard Deviation from the Mean: SDM=

e. Compare the slope you found here with that found in Activity 5.9.1. Does gravitational mass seem to be the constant of proportionality between force and acceleration?

Newton's Second Law

The slope of the linear graph relating the one-dimensional force and the acceleration caused by that force is defined as the *inertial mass*. By defining inertial mass in this way, we have developed sensible definitions of force and mass that lead to Newton's Second Law of Motion for one-dimensional motions in the absence of friction. Newton's Second Law expressed in vector component notation for an object having a total inertial mass of m is simply

$$F_x^{\mathrm{net}} = \sum F_x = ma_x \qquad (5.2)$$

where $\Sigma \vec{F}_x$ is a vector component representing the net one-dimensional force on the object, and a_x is a vector component representing the acceleration caused by the net force.

Inertial and Passive Gravitational Mass

In the last activity you have shown that within the limits of experimental uncertainty inertial and passive gravitational masses are the same. This makes the definition of inertial mass as the proportionality constant between acceleration and force seem less arbitrary.

It is not obvious that these two definitions of mass—passive gravitational and inertial—should yield exactly the same results. This equivalence is assumed in both Newton's theory of gravity and Einstein's general relativistic modifications of it. In fact, sophisticated experiments have shown that within the limits of experimental uncertainty, there is no difference between the two types of mass to within one part in 1011.

Standard SI Units for Mass and Force

As you already know, the Systemè Internationale, or SI system of units provides us with a standard set of units that we often use. This system was established in 1960 to provide units that all scientists throughout the world should use. The SI units for fundamental quantities used in mechanics, including mass, are shown below.

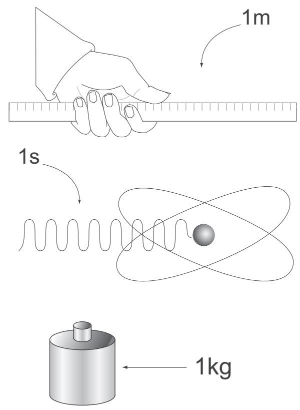


Fig. 5.18.

SI UNITS FOR MECHANICS

Length: A **meter** (m) is the distance traveled by light in a vacuum during a time of 1/299,792,458 second.

Time: A **second** (s) is defined as the time required for a light wave given off by a cesium–133 atom to undergo 9,192,631,770 vibrations.

Mass: A **kilogram** (kg) is defined as the mass of a platinum–iridium alloy cylinder kept in a special chamber at the International Bureau of Weights and Measures in Sévres, France.

The electronic balance and spring scales often used in laboratories have been calibrated using replicas of the "real" standard kilogram mass kept in a vault in France. These fundamental units and Newton's Second Law can also be used to define the Newton as a unit of force. The Newton is defined in terms of mass and acceleration as shown in the box below.

The SI Force Unit Expressed in Terms of Length, Mass and Time Force: A **Newton** (N) is defined as that force, which, when acting on a 1-kg mass, causes an acceleration of 1 m/s/s.

Fig. 5.19.
1 N = 1 kg • m/s/s

Do the Standard Units Work Together?

With the exception of a device called an inertial balance, essentially all the common equipment used in laboratories today measures passive gravitational mass rather than inertial mass. Thus, if you determine the mass in kilograms of your cart and force sensor system using an electronic balance, you can compare it to the inertial mass you found by accelerating your cart system in Activity 5.9.1.

Since you measured forces in Newtons and accelerations in m/s/s, the passive gravitational mass readings from a well-calibrated electronic balance and the inertial mass readings from the slopes of your *F* vs. *a* lines should be the same. Are they?

5.9.3. Activity: Gravitational vs. Inertial Masses in Kilograms

a. Use the electronic balance to determine the passive gravitational mass of your cart with the force sensor attached to it.

$m^{grav} =$ kg

b. What is the inertial mass of your cart with the force sensor attached to it as reported in Activity 5.9.1?

$m^{inertial} =$ kg

c. Are they the same within the limits of experimental uncertainty?

d. What do you think are the possible sources of systematic error and experimental uncertainty in your two measurements?

5.10 SUMMARIZING NEWTON'S FIRST AND SECOND LAWS

The main purpose of Unit 5 has been to explore the relationships between forces on an object, its mass, and its acceleration. You have been trying to develop Newton's first two laws of motion for one-dimensional situations in which all forces lie in a positive or negative direction along the same line and in which there is very little friction present.

5.10.1. Activity: Newton's Laws in Your Own Words

Express Newton's Laws in your own words clearly and precisely.

- The First Law (the one about constant velocity):

- The Second Law (the one relating force, mass, and acceleration):

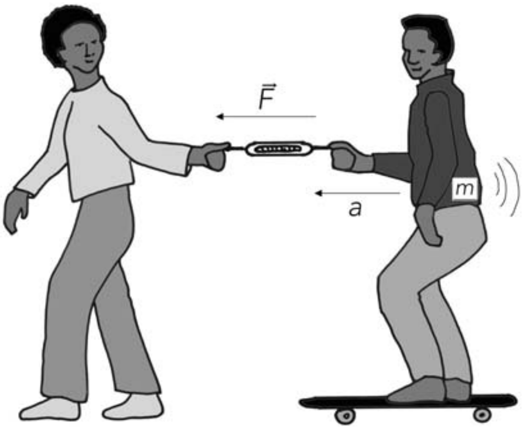


Fig. 5.20.

5.10.2. Activity: Newton's Laws in Equation Form

Express Newton's Laws in equations in terms of the acceleration or velocity vector, the net force on an object, and its mass:

The First Law: If $F_x^{net} = \sum F_x = 0$ then $v_x =$ or

Note: The use of the equal sign does not signify that an acceleration is the same as or equivalent to a force divided by a mass, but instead it spells out a procedure for calculating the magnitude and direction of the acceleration of a mass while it is experiencing a net force. What we assume when we believe in Newton's Second Law is that a net force on a mass causes an acceleration of that mass.

The Second Law: If $F_x^{net} \neq 0$ then $a_x =$

Fig. 5.21. Newton recognized that the laws of motion discovered through the use of applied forces could also be used to discover the nature of gravitational forces and the forces of friction.

Final Comments on Force, Mass, and Motion

You started your study of Newtonian dynamics in this unit by attempting to develop the concept of force. Initially, when asked to define force, most people think of a *force* as an *obvious push or pull* such as a punch to the jaw or the tug of a rubber band. By studying the acceleration that results from a force when little friction is present, we can come up with a second definition of *force* as *that which causes acceleration*. These two alternative definitions of force do not seem to be the same at all. Pulling on a hook attached to a wall doesn't seem to cause the wall to move. An object dropped close to the surface of the earth accelerates and yet there is no visible push or pull on it.

The genius of Newton was to recognize that he could define *net force* as that which causes acceleration. He reasoned that if the applied forces did not account for the degree of acceleration then other "invisible" forces must be present. A prime example of an invisible force is that of gravity—the attraction of the earth for objects.

Finding invisible forces is hard sometimes because some of them are known as *passive* forces because they only seem to act in response to either the motion of an object or other forces on it. Friction forces are one example of passive forces. They are not only invisible, but they only crop up during motions for the purpose of inhibiting the motion. The passive nature of friction is obvious when you think of a person riding on a garbage bag and sliding along the floor at constant velocity under the influence of an applied force.

According the Newton's First Law, a person moving at a constant velocity must have no net force on her. Newton thought that the applied force in one direction had to be opposed by a friction force acting in the other direction to oppose her motion. The friction force must be passive because, if the applied force is discontinued, the friction force does cause the sliding person to slow down until she has no motion. Then the friction force stops acting. If it didn't stop acting, the person would slow down and then turn around and speed up in the opposite direction. This doesn't happen!

During the rest of our study of the Newtonian formulation of classical mechanics your task will be to discover and invent new types of active and passive forces so that you can continue to explain and predict motions using Newton's Laws. In the next unit you will be using Newton's Laws to explain why sliding masses that have no visible forces on them slow down and come to rest, and to learn why masses fall when dropped close to the surface of the Earth. You will also learn how to extend Newton's Laws to two-dimensional situations when the motion of an object and the forces that act on it *do not lie along the same line.*

24th General Assembly of IUPAP (2002)
Summary Resolution on Enhancing the Role of Women in Physics

Preamble

Physics plays a key role in understanding the world we live in, and physicists contribute strongly to the welfare and economic development of nations. The knowledge and problem-solving skills of physicists are essential in many professions and industries and to society at large. To thrive in today's fast-changing, technological world, every country must achieve a highly educated population of women and men, fully engaged in making decisions important to their well being. Knowledge of physics is thus an important part of general literacy for every citizen. In addition, advancing physics understanding is an exciting intellectual challenge that benefits from the diverse and complementary approaches taken by both women and men from many cultures.

Women can and do contribute to this quest and, through physics, to the welfare of humankind, but only in small numbers: women are an underutilized intellectual reserve. Only when women participate fully as researchers in the laboratory, as scientific leaders and teachers, and as policy makers will they be equal partners in a technological society. Studies by Governments, Academies, major Universities, and many Physical Societies have shown that this is not the case today.

To examine the problem, and make recommendations on its amelioration, IUPAP convened an International Conference on Women in Physics. It took place in Paris, France, 7-9 March 2002, and was attended by over 300 physicists from 65 countries. The conferees examined the issues in depth and generated a set of resolutions aimed at establishing fully equal opportunity for success in physics independent of gender.

Resolution

The members of IUPAP, believing that it is important to physics to bring more women into its mainstream and leadership, endorse the resolutions adopted unanimously by the first International Conference on Women in Physics. Specifically, IUPAP urges that:

1) **Primary and Secondary Schools** should have policies and procedures that give the same opportunities and encouragement to the study of physics by girls and boys
2) **Colleges and Universities should**:
a. ensure that their policies and procedures give female and male students equal opportunities for success, and
b. ensure that their policies and procedures are such that female and male faculty and staff are, through transparent policies, treated with equity with respect to recruitment, promotion, teaching schedules, research facilities, and roles in governance.
3) **Research Institutes and Industry** should ensure that policies are adopted and enforced regarding gender equity in recruitment and promotion to all levels.
4) **Scientific and Professional Societies** should foster gender equity by having an identified group examining policies and procedures, making available statistics on the participation of women in physics at all levels, identifying leading women physicists and promoting them as role models, including women on program committees and as speakers at meetings and conferences, and including women in society governance.
5) **National Governments** should ensure that women have the same access and opportunity as men in research and advanced teaching, that women are included on national planning and review committees, and that funds are awarded only to organizations that have policies of gender equity.
6) **Funding Agencies** should ensure that there is no gender bias in the broad based general grant funding process, that competitions are open and widely publicized, that criteria for funding are clear, and that women are included on review and decision making committees. Limits on age of eligibility or grant duration that seriously disadvantage applicants taking family leave should be reconsidered. Statistics should be made available giving by gender the proportion of successful applicants.
7) **All Institutions** should note that family oriented policies and practices such as flexible work schedules, opportunities for dual career families, and the availability of child care facilities have been demonstrated to increase the opportunities for Women in all fields of science and technology. All institutions should reexamine their practices in this area.

It is further resolved that IUPAP's Liaison Committees will transmit the report of the Conference on Women in Physics and the above resolution to their Adhering Bodies, and that the Secretariat will transmit it to other Scientific Unions and International Organizations. Further, the proceedings of the International Conference on Women in Physics should be made known and widely available.
The General Assembly recommends that Adhering Bodies appoint women to Liaison Committees, that gender be a consideration in nominations to Commissions and the Council, and expects that IUPAP sponsored conferences have women as members of their program committees.

Resolution for the IUPAP 26th General Assembly
Submitted by the
3rd IUPAP International Conference on Women in Physics
Seoul, Korea, October 7-10, 2008

Since the 1st IUPAP International Conference on Women in Physics (Paris, March 2002) and the 2nd Conference (Rio de Janeiro, May 2005) progress has continued in most countries and world regions to attract girls to physics and advance women into leadership roles, and many working groups have formed. The 3rd Conference (Seoul, October 2008), with 283 attendees from 57 countries, was dedicated to celebrating the physics achievements of women throughout the world, networking toward new international collaborations, building each participant's capacity for career success, and aiding the formation of active regional working groups to advance women in physics. Despite the progress, women remain a small minority of the physics community in most countries.

Only when women of all races and nationalities are included within the physics community will the global society benefit fully from the contributions physics offers to economic development and to the solution of major challenges, such as energy, health, climate change, water, education, and sustainability, that transcend national boundaries. To accelerate progress, both men and women in physics must champion this agenda. The representatives assembled in Seoul unanimously recommend the following actions to the IUPAP 26th General Assembly in Tsukuba, Japan:

1. **Promote through the IUPAP Liaison Committees and physical societies the formation of additional regional or national working groups for women in physics.** These working groups would assist worldwide in the efforts to increase the participation of women, while being a resource to attract, retain, and advance women in physics.

2. **Publicize site visits as an effective tool for improving the "climate" of physics workplaces, and encourage their implementation to help the workplaces become more supportive of both women and men.** For a site visit, an institution or physics department invites a team of physicists to assess the work environment for women and to give advice for improvements in gender equity.

3. **Actively encourage organizers of IUPAP-sponsored conferences to provide, associated with the conference programme (a) professional development workshops for attendees and (b) outreach activities aimed at the public and to engage both girls and boys from an early age in the excitement of physics.**

4. **Charge the IUPAP Working Group on Women in Physics (a) to oversee the administration of a global survey of physicists in 2009, (b) to continue to assess the progress of women in physics, (c) to make useful resources available globally through the internet, (d) to organize the 4th International Conference on Women in Physics in 2011, and (e) to report at the 27th IUPAP General Assembly in 2011.**

5. **Urge IUPAP Liaison Committees and physical societies to take the leadership in their countries to encourage broad participation of their members in the global survey of physicists.**

Resolution for the IUPAP 25th General Assembly

Submitted by the

2nd IUPAP International Conference on Women in Physics

Rio de Janeiro, 23-25 May 2005

Since the 1st IUPAP International Conference on Women in Physics (Paris, March 2002), more attention has been paid to including women in physics in many countries. Although some noticeable progress has been made, much more remains to be done before physics and its use in the countries of the world can benefit fully from the ideas and efforts of women. To promote the recruitment, retention, and advancement of women of all races and nationalities in physics, the representatives of the physics communities from 42 countries assembled in Rio de Janeiro unanimously recommend the following actions to the IUPAP 25th General Assembly in Cape Town, South Africa:

1. Request all IUPAP Liaison Committees to work toward catalyzing women's full participation in physics.

2. Write to the physical societies among its Members urging them to work harder to include women in their activities and reward systems.

3 Recognizing the efforts that IUPAP has already made to make sure that all IUPAP conference include women on program committees and among invited speakers, continue to work with conference organizers to promote the inclusion and encouragement of women.

4 Continue to work to increase the presence of women among its leadership.

5. Encourage the IUPAP Working Group on Women on Physics to consider developing training modules on gender and race equity in physics, on physics education pedagogies and curricula, and on the recruitment, retention, and advancement of women and on translating them into many languages.

6. Encourage the IUPAP Working Group on Women in Physics to oversee a thorough international survey of the status of women in physics in 2007, organize the 3rd International Conference on Women in Physics in 2008, and report at the 26th IUPAP General Assembly in Fall 2008.

Reconfigurable Virtual Instrumentation based on FPGAs

New opportunities

in scientific instrumentation

I. Brief review of FPGA trends

II. A case study to illustrate some new related opportunities

*The **R**econfigurable **V**irtual **I**nstrumentation project*

What is an FPGA?

FPGA: **F**ield **P**rogrammable **G**ate **A**rray

Essentially it is

A 2D collection of interconnectable and configurable logic blocks

+

A flexible interface

What is an FPGA today?

Some New Features:

- True dual port RAM (several Mb)
- Clock management units (DLL, PLL)
- Optimized arithmetic blocks (multipliers)
- Embedded processors (PowerPC)
- Highly specialized In-Out ports (Gbits/sec)

What an FPGA will be in the future?

- More specialized arithmetic units
- Analog blocks (A/D, D/A)
- More optimized for System-on-Chip (SOC) implementation
- Larger number of embedded processors
- Embedded peripheral controllers

What is the main difference between microprocessors and PLDs ?

Examples:

Processors

- MicroControlers
- DSP
- General Purpose

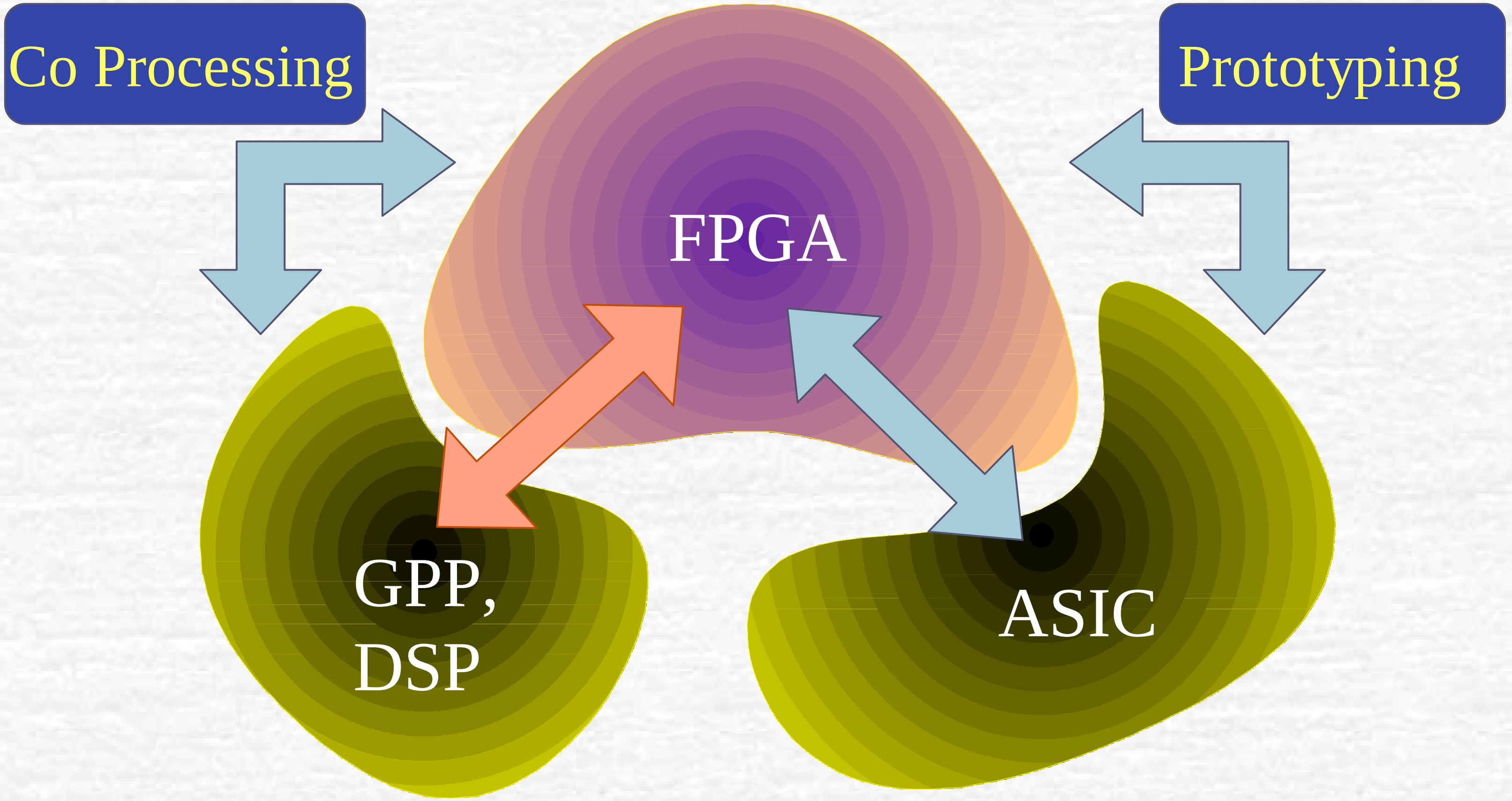
PLD

- Pal, Pdl, etc (simple)
- CPLDs (complex)
- FPGAs (more complex)

Comparison

	Microprocessor	FPGA
Optimized	to execute an instruction set	to implement a wide variety of designs
Configuration (Hardware)	Very little Static	Extremely versatile Partial and dynamic reconfiguration
Programming	High level language Compilers	Depending on design
Operation	Mainly sequential Some parallelism	Essentially parallel
Input Output	Electrically and Logically Fixed	Extremely versatile

FPGA are growing faster than traditional alternatives like ASIC and Microprocessors in terms of performance-cost ratio.



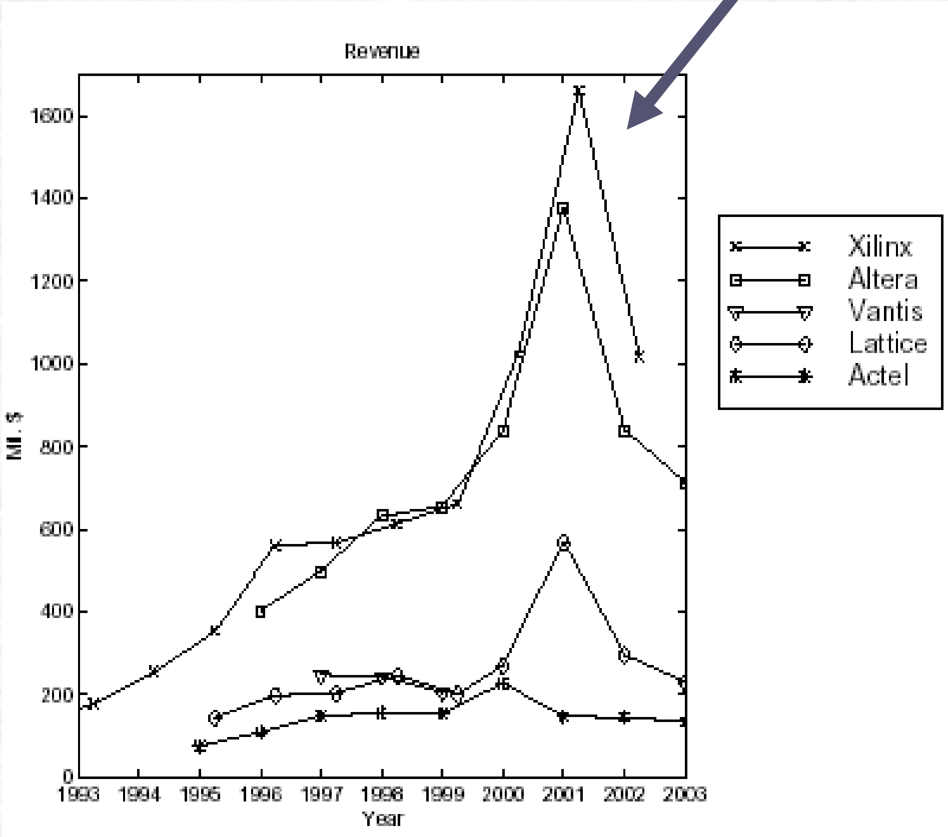
Revenues of the top five PLD vendor (1993-2003)

Several factor have contributed to this

Internet bubble

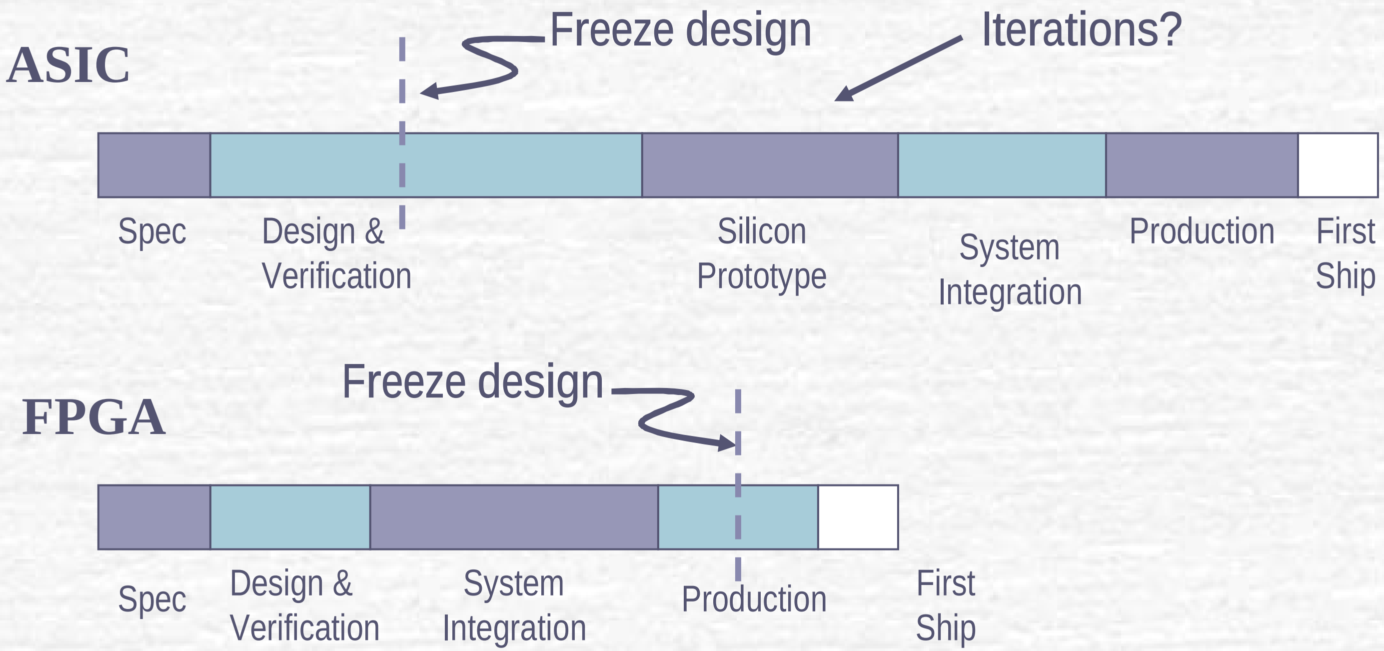
- Reduction of size and power dissipation
- Higher throughput
- In-circuit reprogramability
- Lower NRE and total costs

  (FPGA-ASIC crossover growing)
- Almost free CAD tools
- Fast prototyping time



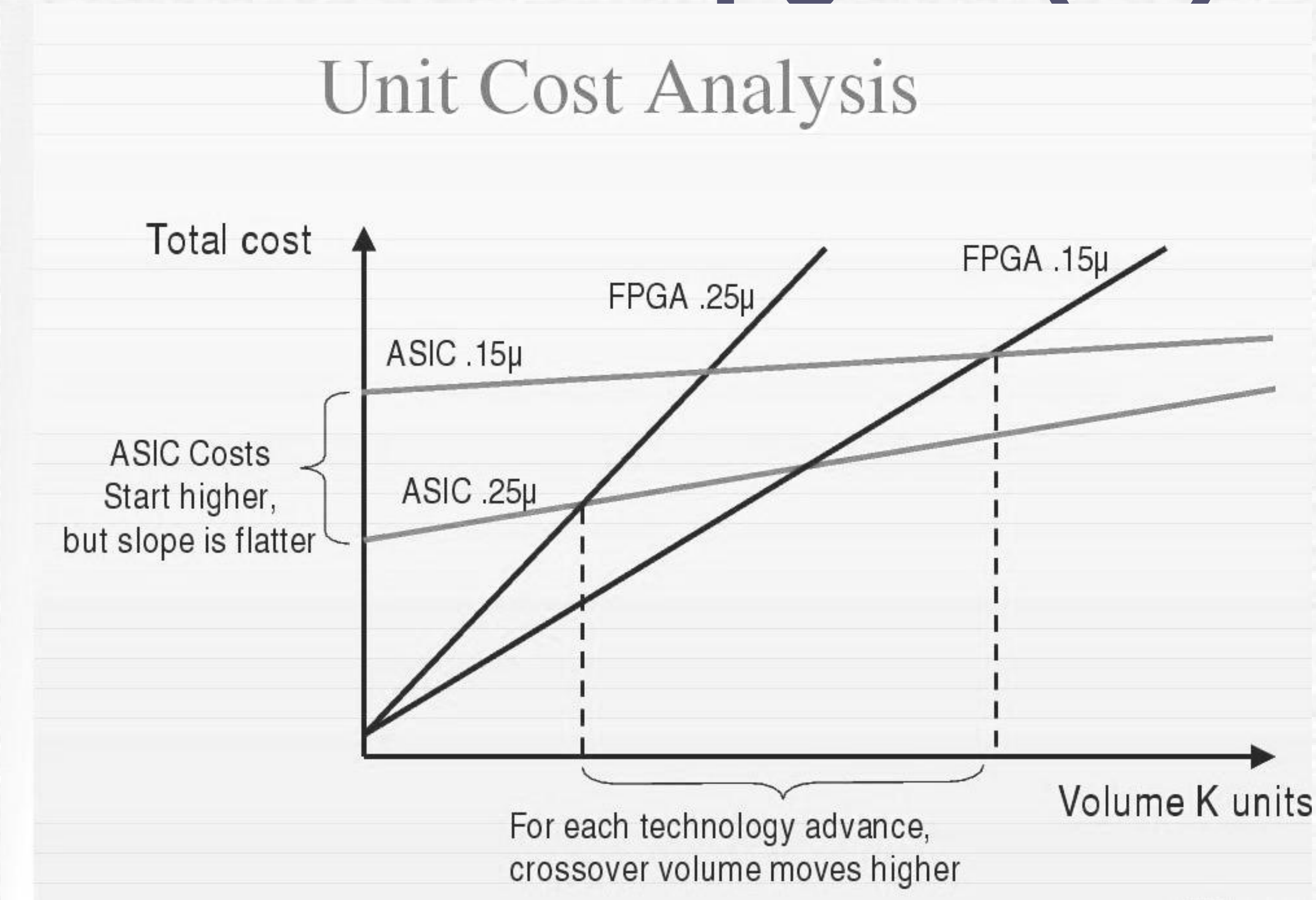
Asics vs. Fpgas (I)

Time to Market: Design Cycle



- ASIC methodology is very unforgiving
- FPGA flexibility allows late design changes

Asics vs. Fpgas (II)

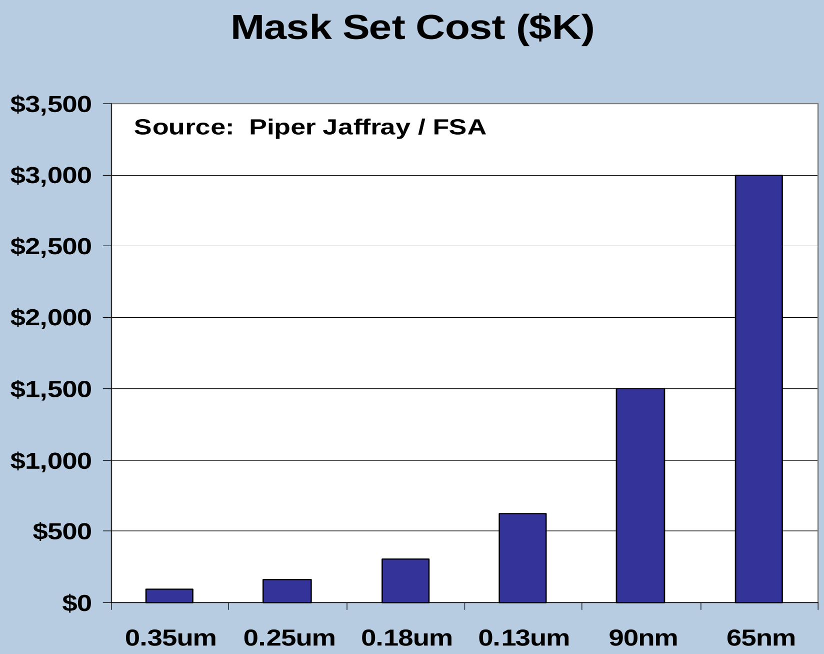


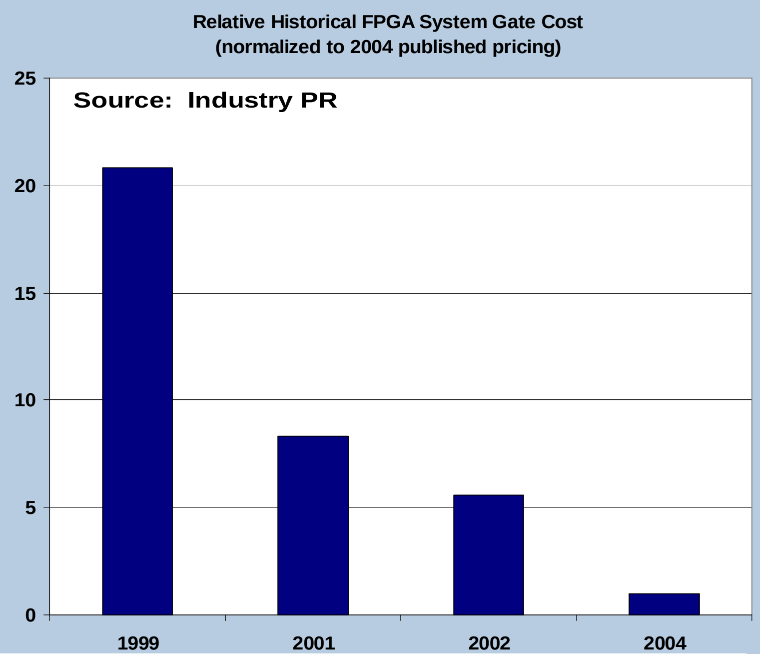
Asics vs. Fpgas (III)

FPGA vs ASIC Cost

90nm ASIC: ~$3 of amortized cost to ASP of a 500k unit socket

Process + Architecture + Volume = greatly reduced prices





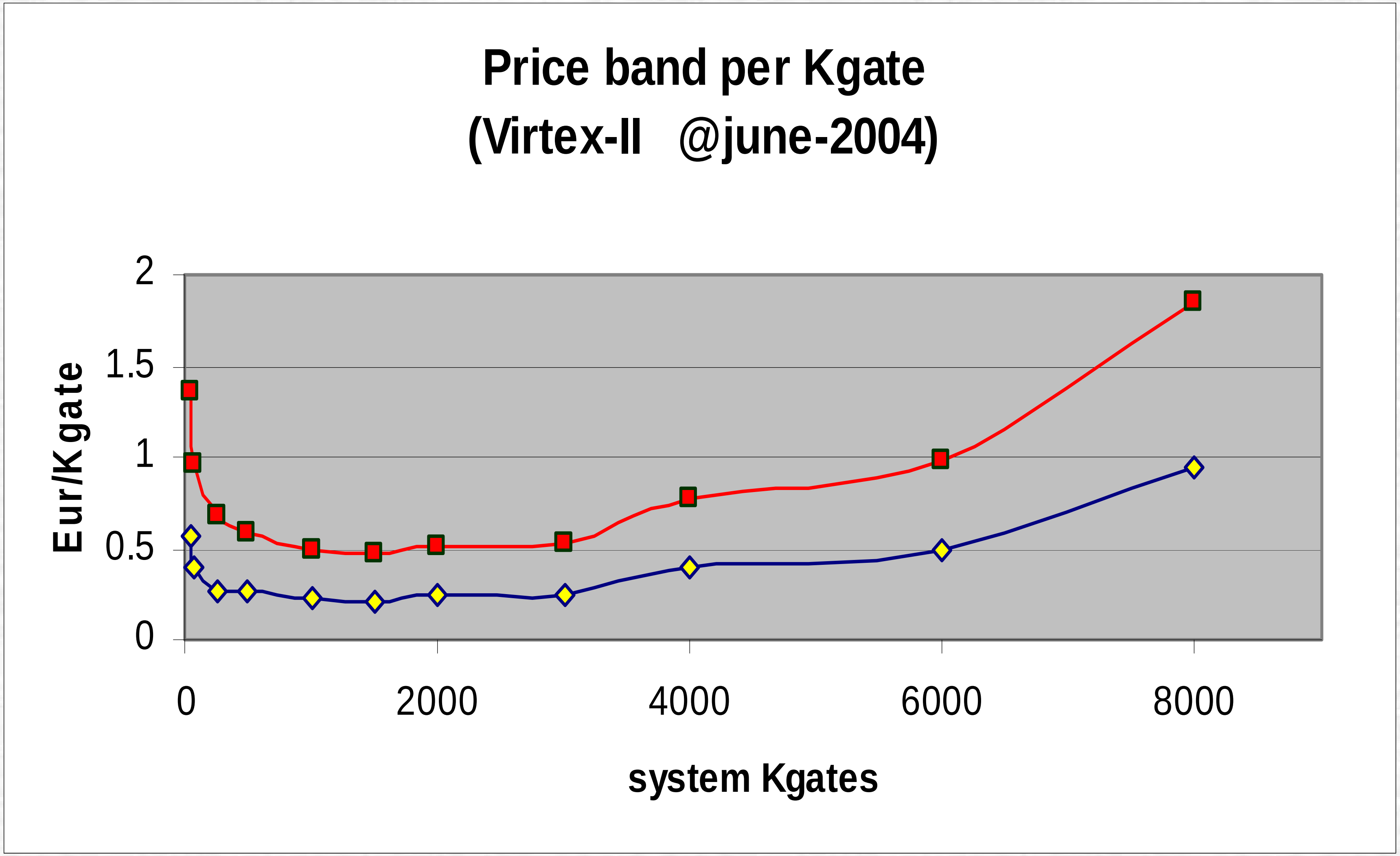
Some numbers

(Xilinx Virtex-II)

Device:	XC2V1000	XC2V8000
• User In-Outs:	432	1200
• Number of slices*:	5000	46000
• 18-bits Multipliers:	40	168
• CLB Array:	40 x 32	112 x 104
• System Memory:	0.7 Mbit	3 Mbits
• Approx. Price**:	~0.4 K$	~10 K$

* Elemental reconfigurable logic unit (LUT + FF)

** Lowest prices start from less than 5$ for some FPGAs


Price band per Kgate
(Virtex-II @june-2004)
Eur/Kgate
2
1.5
1
0.5
0
0
2000
4000
6000
8000
system Kgates

Let us have a closer look at an FPGA

(A Virtex100 design through Foundation 2.1i)

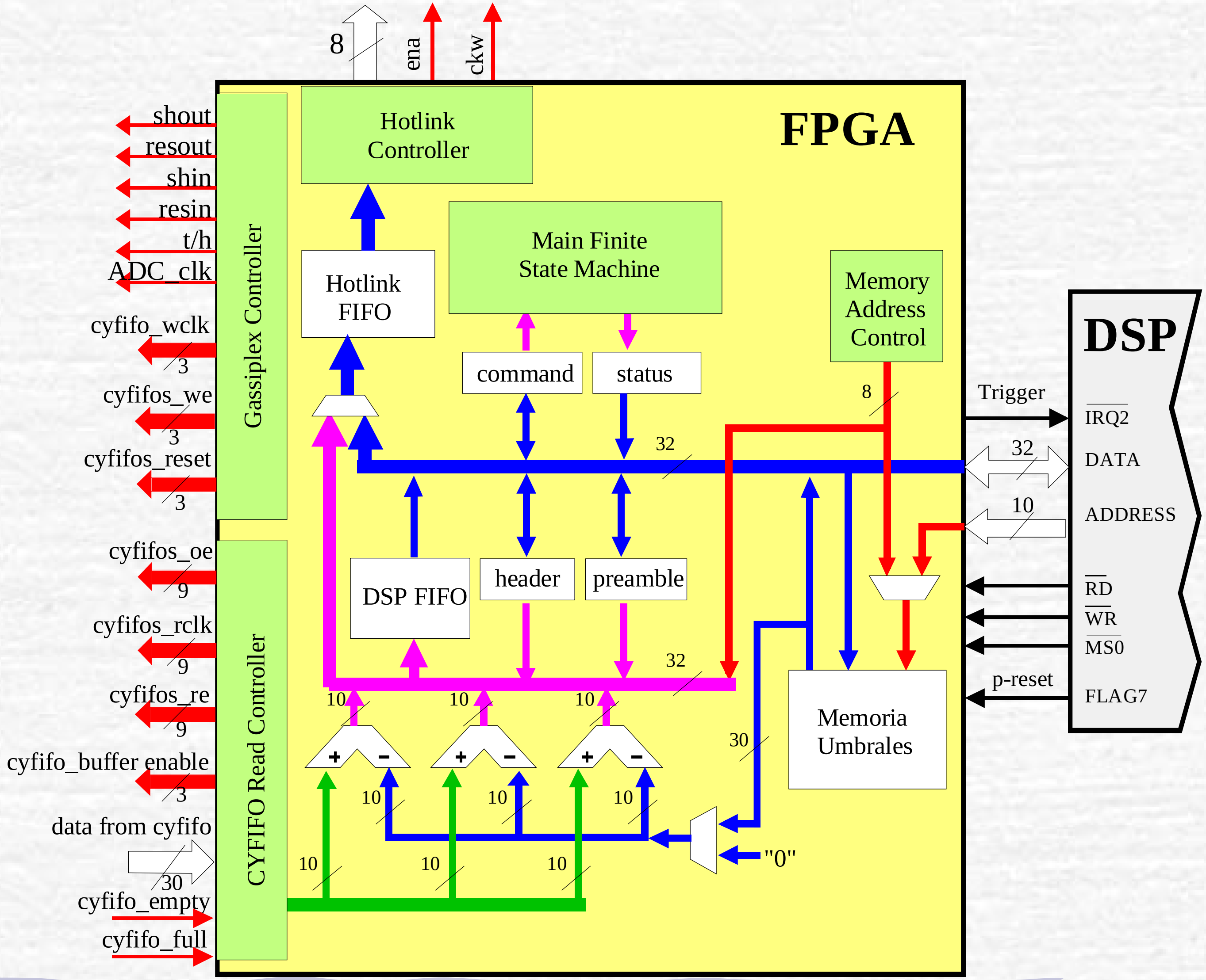
Example:

COMPASS BORA FPGA Design on a Virtex 100

* Among the largest FPGAs in 2000

* Among the smallest FPGAs in 2008

Global Architecture of BORA-FPGA



More Numbers …

(Virtex-II Pro)

Feature/Product	XC 2VP40	XC 2VP50	XC 2VP70	XC 2VPX70	XC 2VP100
Logic Cells	46,632	53,136	74,448	74,448	99,216
BRAM (Kbits)	3,456	4,176	5,904	5,544	7,992
18x18 Multipliers	192	232	328	308	444
Digital Clock Management Blocks	8	8	8	8	12
Config (Mbits)	15.56	19.02	26.1	26.1	33.65
PowerPC Processors	2	2	2	2	2
3.125 Gbps RocketIO Transceivers	12	16	20	0	20
10.3125 Gbps RocketIO X Transceivers	0	0	0	20	0
Max Available User I/O	804	852	996	992	1164

How to deal with such a complexity ?
How to get the most out of it ?

- ✓ Rigorous Top-Down Design Methodology using HDL
- ✓ CAD tools for simulation and synthesis
- ✓ "***Design for reusability"*** strategy
  - Standards, guidelines, interfaces, protocols, etc
- ✓ ***Intellectual Property*** *blocks* (*IP* ***cores***)

What can be achieved ?

- Co processing to speed up DSP and GPP computations
- Real Time systems for high performance data acquisition and process control
- Reconfigurable computing (Quantum Monte Carlo simulations, Pattern recognition, high speed data compression-decompression)
- In general: Radar/Sonar, Telecom, Medical Instr., Sci. Instr., Robotics, Ad hoc high performance instrumentation (*CASIS, new SDD readout*)
- **Reconfigurable Instrumentation** (ICTP RVI System)

A BLOCK-BASED OPEN SOURCE APPROACH FOR A RECONFIGURABLE VIRTUAL INSTRUMENTATION PLATFORM USING FPGA TECHNOLOGY

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CA, USA

Proposal for an RVI system

Goal

low-cost reusable hardware/software platform for the implementation of multiple electronic and scientific instruments

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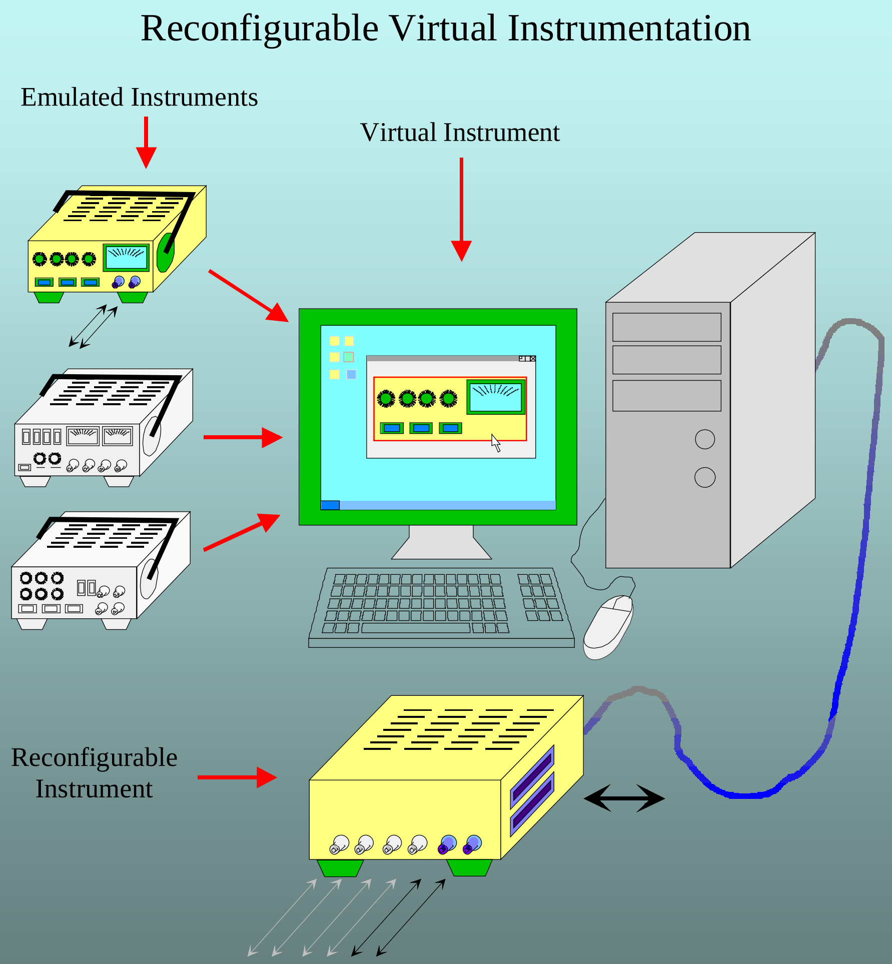
An artistic view of an RVI System



- The RVI system can be seen as a “magic-box” connected to a PC through a standard port
- High-level software application
  - select a virtual instrument from a library of instruments
  - configures the RVI system to convert it into the selected instrument with its associated console

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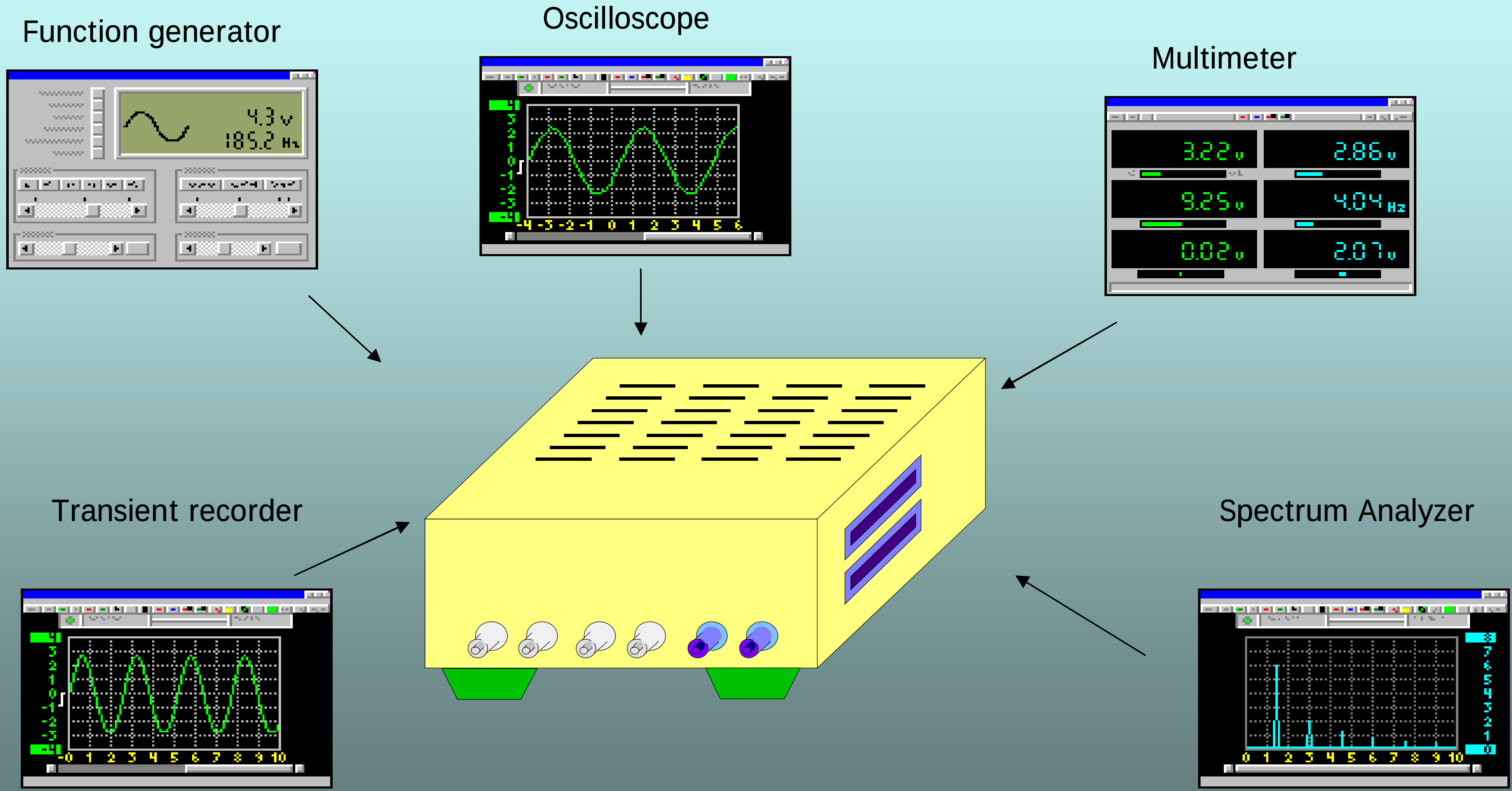
Reconfigurable Virtual Instrumentation



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Key aspects for an RVI system

Hardware & Software modularity

- Block-based design methodology
- Hierarchical structure

Common standardized global architecture

- Block interfaces definition
- Clear mechanism of blocks interaction

Open Source & Open Cores

- Sharing the design effort and results by a large community of users and contributors with different expertise's and backgrounds (EE, Physicist, Comp. Sci. , DSP experts, etc)

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RVI SYSTEM

- ***Reconfigurable Instrument*** (the magic box)
  – a versatile hardware device that can be reconfigured into different electronic instruments using a software tool

- ***Virtual Instrumentation***
  – a hardware and software combination that allows the emulation of an instrument through a custom virtual console and a graphical user interface

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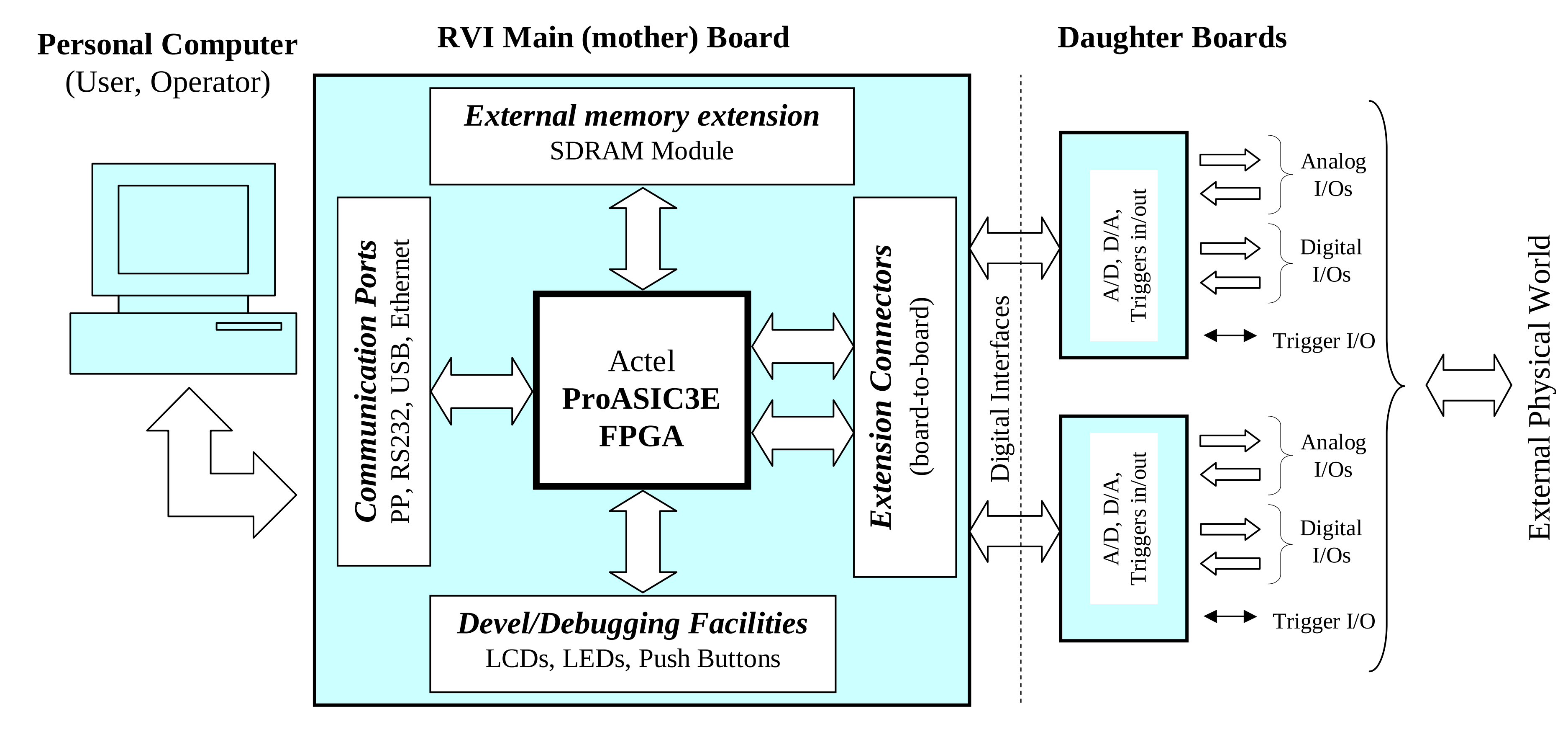
High-Level RVI System Architecture

- Hardware sub-system
  - RI connected to a PC through a physical connection.
- Software sub-systems
  - software related to the PC
  - the code corresponding to the FPGA of the RI

RVI Hardware Sub-System



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Reconfigurable Instrument

- **RVI mother board**
  - FPGA device (ACTEL AP3E family)
  - a block of communication ports
  - an extension memory
  - debugging facilities and miscellaneous components
  - two high quality board-to-board connectors with 54 pins directly connected to the FPGA gp-I/O

- **Low Performance Daughter Board**
  - dual channel 10-bits 20 MSPS ADC (AD9201, Analog Devices),
  - dual channel 14-bit 1 MSPS DAC (LTC1654, Linear)

- **High Performance Daughter Board**
  - single channel 14-bits 125 MSPS ADC (LTC2255, Linear)
  - single channel 16-bit 50 MSPS DAC (LTC1668, Linear)

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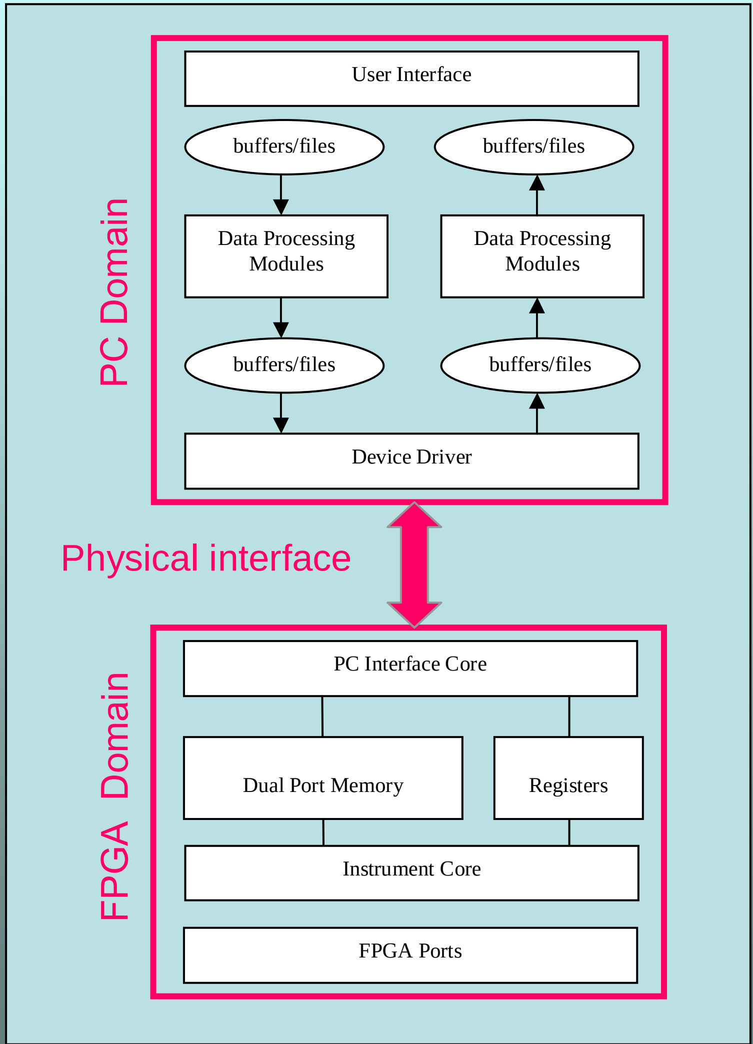
The Global Software Architecture



- ***Computer Software***
  user interface, port management, and offline data elaboration programs and utilities

- ***Synthesizable Hardware Description Code***
  management of the physical connection with the PC, ADC and DAC operations, data generation and acquisition, real-time online data processing, and on-board real time data handling

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The Computer Software

- collection of independent modules hierarchically organized
- basically, the CS provides:
  - a generic RVI graphical and textual user interface
  - a library of virtual instruments with custom user interfaces
  - data storage facilities
  - physical communication control (drivers)
- optionally, the CS could also provide:
  - an internet connection for remote instrument control and operation
  - specific data analysis packages and other facilities
  - a friendly interface with a general purpose in-chip logic analyzer for development and debugging.

Synthesizable Hardware Description Code

- basically, the SHDC provides:
  - PC-FPGA communication block
  - the instrument core
  - external hardware specific interface block.

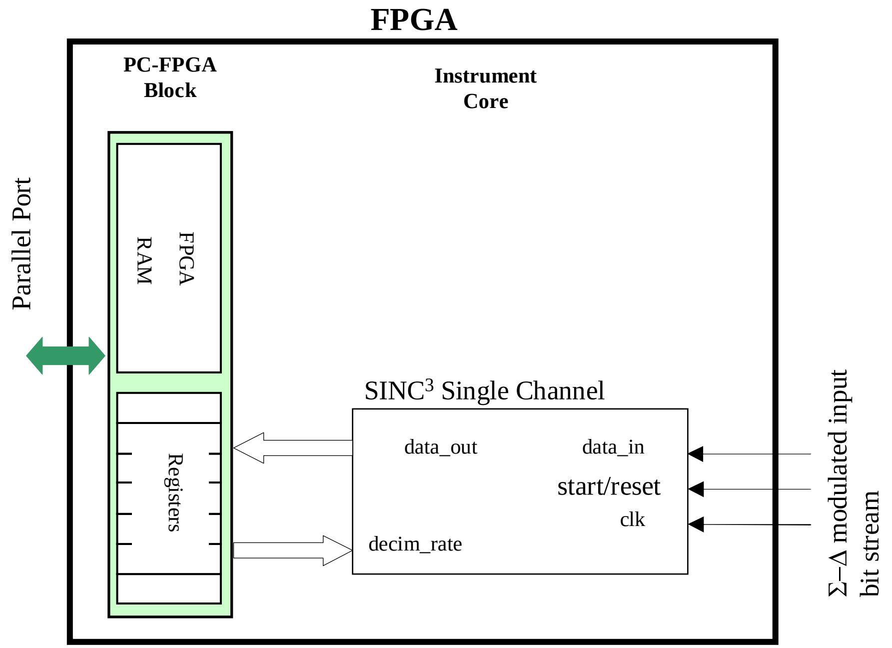
Integrating a reconfigurable instrument core in an RVI system

- The core must comply with
  - the standardized interfaces of the PC-FPGA communication block and the external hardware specific interface block
  - a common mechanism of interaction

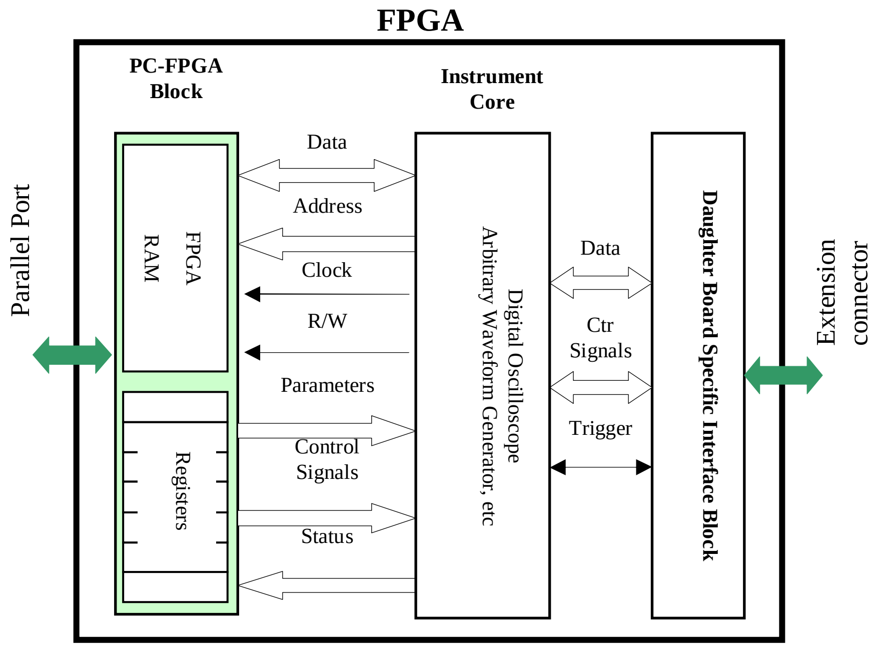
- If the three main blocks: PC-FPGA communication block, instrument core, and the external hardware interface respect both previous conditions, then each block can be updated or upgraded independently and can be reused in different contexts.

Architecture for Single Instruments

Implementation Examples



Block diagram of the FPGA architecture for a Reconfigurable Σ–Δ demodulator for Anolog to Digital conversion.



Block diagram of the FPGA architecture for a Reconfigurable Virtual Arbitrary Waveform Generator or Digital oscilloscope.

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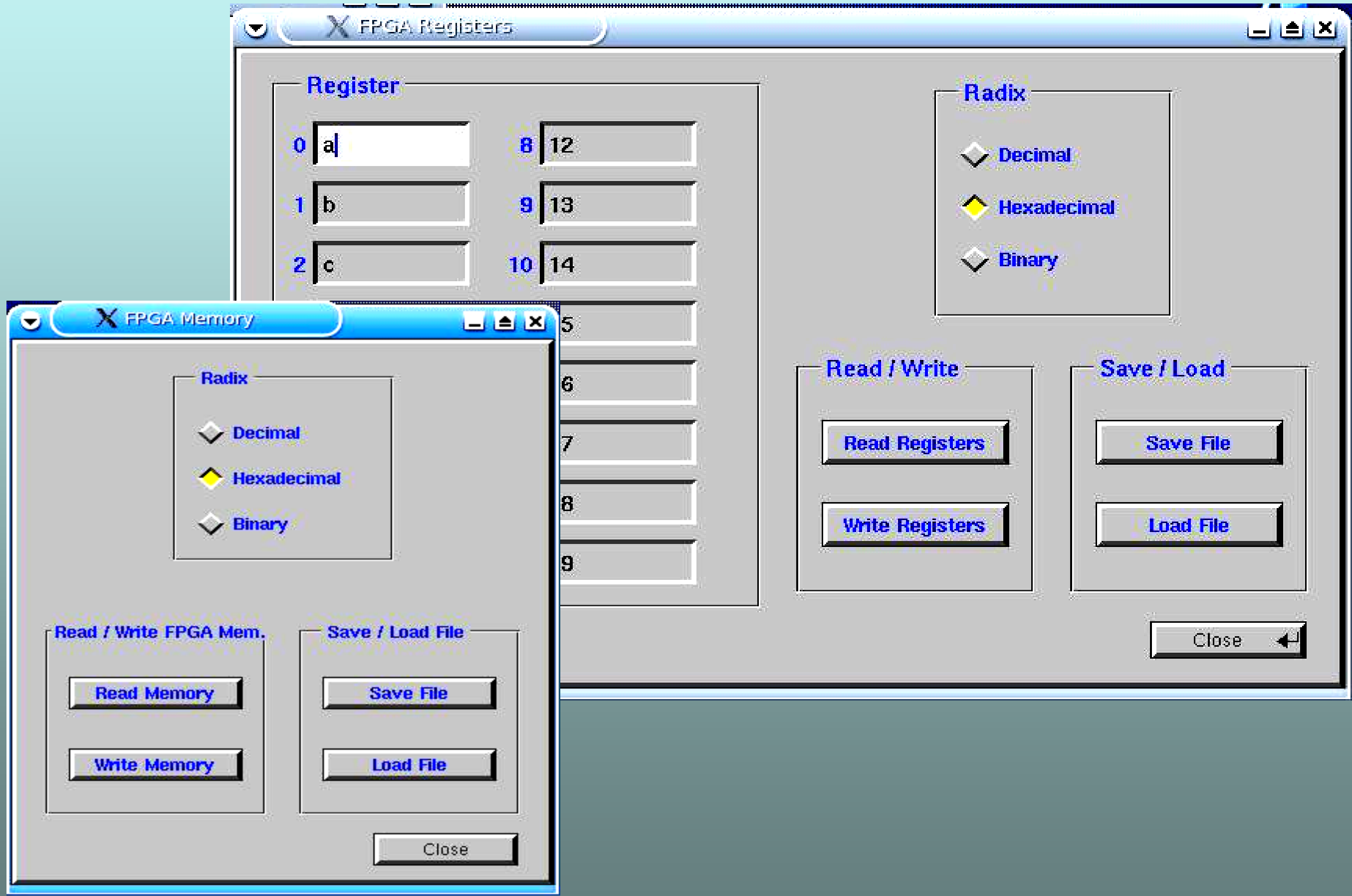
General Purpose Debugging Interface



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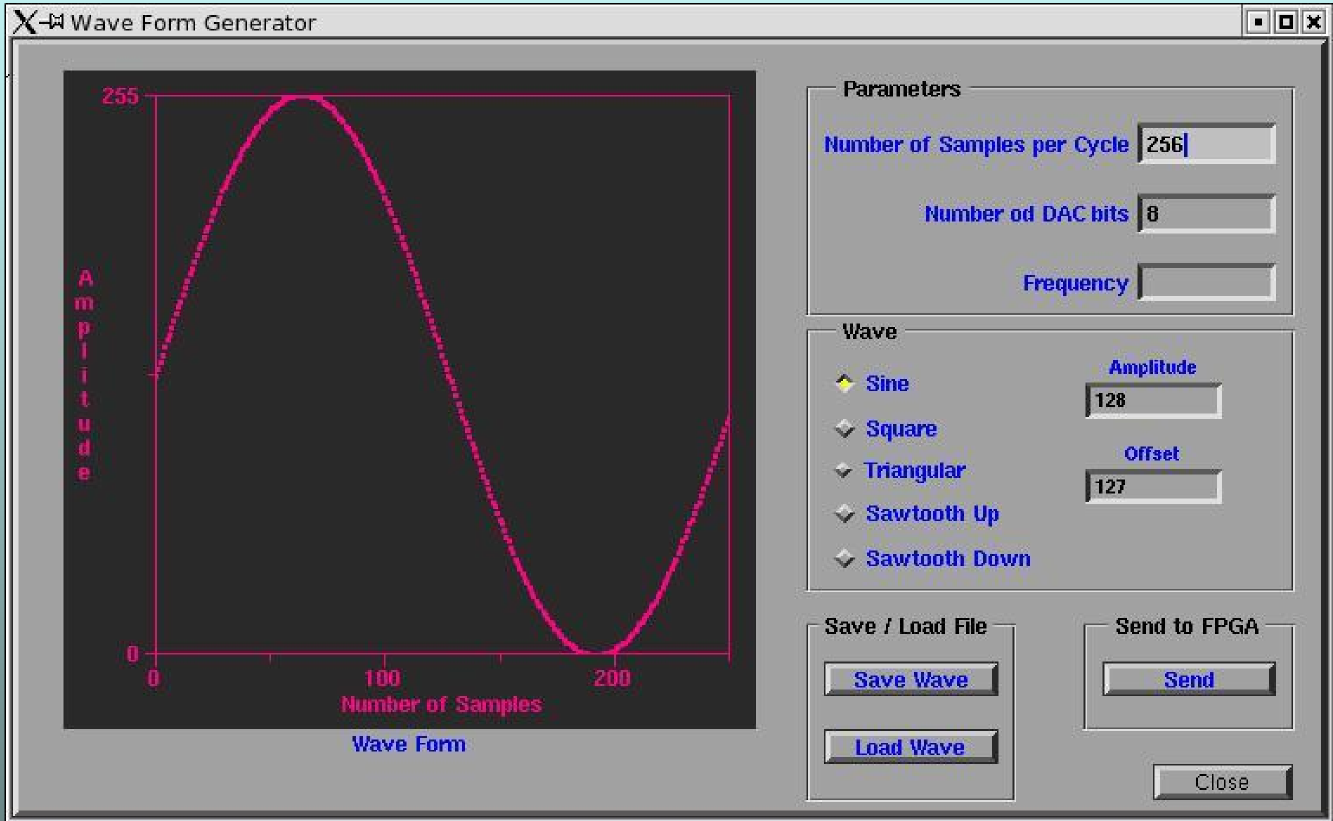
GUI for a Wave Form Generator



- DAC (Linear 1668)
  14bit @ 1MSPS

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Conclusion (1)

- **FPGA is a key technology for TW countries**
- **FPGA technologies are opening up new opportunities including in the field of scientific instrumentation**

Very good hardware cost/performance ratio

High effort required to develop all the software/hardware chain of new systems

Wide freely available collection/library of standardized functional blocks (at PC and FPGA levels)

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Conclusion (2)

- **A Reconfigurable virtual Instrumentation system based on FPGA is possible now**

Many areas of applications from basic research to Industry

Emulation of:

- standard general purpose instruments
- sophisticated instrumentation for custom specific applications

Low cost solution for universities and research institutions in developing countries

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Conclusion (3)

- The Reconfigurable Instrument could be seen as a parallel coprocessor of the PC

Reconfigurable Computing

Accelerate execution of time consuming or time critical tasks
- online digital signal processing
- real time hardware control

Conclusion (4)

- **Open Source & Open Core Approach**

Is Affordable and Accessible; Production, Distribution and Exchange of IP cores can be done through websites

Stimulates Scientific Research and Production of Intellectual Properties

Encourages South-South and Industry-Academy cooperation

Creates new business opportunities based on free software and double licensing schemes

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Visualizing motion in potential wells

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The concept of potential-energy diagrams is of fundamental importance in the study of quantum physics. Yet, students are rarely exposed to this powerful alternative description in introductory classes and thus have difficulty comprehending its significance when they encounter it in beginning-level quantum courses. We describe a learning unit that incorporates a sequence of computer-interfaced experiments using dynamics or air-track systems. This unit is designed to make the learning of potential-energy diagrams less abstract. Students begin by constructing the harmonic or square-well potential diagrams using either the velocity data and assuming conservation of energy or the force-displacement graph for the elastic interaction of an object constrained by springs or bouncing off springy blocks. Then, they investigate the motion of a rider magnet interacting with a configuration of field magnets and plot directly the potential-energy diagrams using a magnetic field sensor. The ease of measurement allows exploring the motion in a large variety of potential shapes in a short duration class.

I. INTRODUCTION

The concept of potential-energy diagrams is of fundamental importance to teaching of physics. In many situations, instead of Newton's law, energy considerations are used as the basis for analyzing the behavior of an object interacting with a given system. The procedure is to consider how the potential energy of the object varies as a function of distance. Given this information and the total energy of the object, all other details of behavior can be deduced. This method is adopted in quantum physics for studying the motion of microscopic particles. Students in beginning-level mechanics courses, however, are rarely exposed to this powerful alternative description of motion. Thus they frequently have difficulty comprehending the significance and power of potential-energy functions when they first encounter them in introductory quantum mechanics.

We have attempted to remedy this situation by creating a set of experiments and a teaching unit designed to provide beginning-level students with an early exposure to the idea of potential-energy diagrams. Familiar mechanical systems are used to create potential shapes akin to those encountered in models of atomic and nuclear interactions. Observing and interpreting motion in these potential wells, on the one hand, and establishing the relationship between the operative forces and the potential energy on the other, provides a straightforward understanding of an otherwise abstract concept.

A survey of literature shows that very few earlier attempts have set up experiments to study motion in potential wells.[1–3] The most comprehensive effort using this approach is in the work of Saraf *et al*.[4] The essential idea in all these laboratory investigations is to place magnets along an air track to create a variety of potential barriers and wells. The previous developers used a photointerrupt and timing device to measure directly the velocity of a glider at a number of locations along its path. Then assuming conservation of energy, their students determined the potential energy as a function of distance. Sometimes for the sake of economy a single sensor was employed. Then, the experiment had to be repeated a large number of times with the sensor placed at different locations. This procedure made the experiment rather tedious, and variations in initial conditions usually led to a relatively large scatter in the data.

Prior to commercial proliferation of computer-based laboratory equipment, designing an experiment that could yield the velocities at different locations along the path in a single run was not trivial. Thus all such earlier work employed dedicated transducers and computer programs not commonly available off the shelf. For instance, Eckstein[3,5] used a specially designed motion detector which is essentially a Mylar strip crossed by regularly marked black stripes. As the object was in motion, the number of stripes passing through two high resolution photocells was counted as a function of time. The students ported these data into a spreadsheet to compute the velocities. The procedural problems inherent in these methods make the experiments rather complicated in practice and difficult to execute in a typical undergraduate class.

While magnetic interactions generate very interesting shapes for the potential function, the force field of an arbitrary configuration of magnets can be rather complicated and the motion, difficult to predict. For this reason, we recommend introducing the notion of potential well using the more familiar elastic interactions at the outset. In our approach, students first construct potential wells for a simple physical system such as a cart oscillating along a track constrained by springs or moving freely along a track and bouncing off springy blocks placed at the ends of the track. Once the students have built sufficient competence in identifying the forces and interpreting the corresponding potential-energy diagrams in these cases, they explore the motion in more complicated potential shapes generated by configurations of magnets.

We have designed our experiments using transducers and data acquisition systems readily available from commercial suppliers. However, the setups and the measurement procedures incorporate several novel features. In the following sections, we provide details of experiment design and outline the learning paths envisaged.

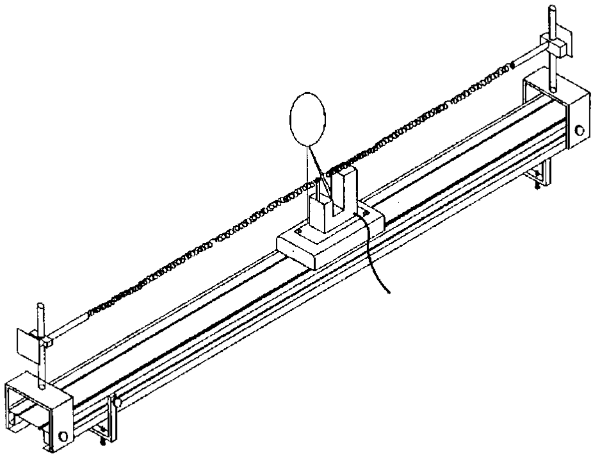

Fig. 1. The experimental arrangement for investigating potential-energy diagrams using dynamics cart and springs.

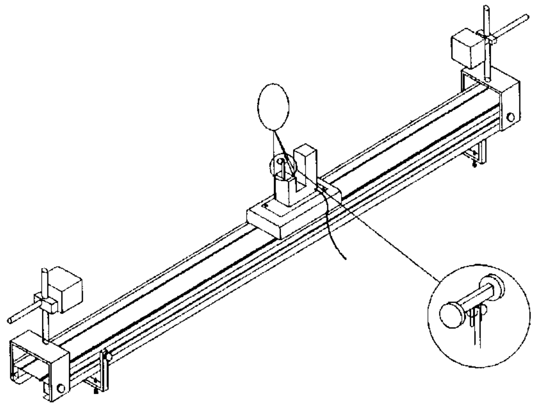

Fig. 3. A dynamics cart is a deep square well potential.

II. EXPERIMENTS

A. Elastic interactions

We have used the data acquisition system ULI, the program MOTION, the Student Force Sensor and the Motion Detector, all available from Vernier Software,[6] to record the motion and the force in real time. The experiments use either the dynamics cart or the air-track system from PASCO scientific.[7] The advantage of using the dynamics cart is that the setup is relatively inexpensive, involves few adjustments, and is more robust for classroom usage, while the advantage of using the air track is that friction is smaller; consequently, the crucial assumption of conservation of energy holds better and the motion can be observed over a longer duration of time.

1. Spring oscillator

Figure 1 gives a schematic diagram of the basic setup with a cart held to the two ends of the track by a set of matched springs. The Student Force Sensor is mounted on the cart using a flat plate with a small post on which the sensor can be screwed. This plate also mounts another post on which a disk is fixed at a suitable height to reflect the signal from the ultrasonic motion detector. Our investigations show that a circular disk works quite well for the purpose. The springs attach on one end to the hooks welded by the manufacturer to the cantilever beam of the force sensor and on the other to specially designed adjustable clamps fixed at the two ends of the track. The end clamps allow for easy alignment of the springs. Care is also taken to eliminate any wobble of the force sensor or the reflector to ensure low-noise data for the position and the force.

When an air-track system is employed, because of the added weight, the glider cannot float easily if the commercially available students' force sensor is mounted on it. An excellent and relatively inexpensive alternative is to use the strain gauge force sensor kit[8] available from Vernier and fabricate a much lighter force sensor. This kit contains a set of strain gauge transducers, the circuit diagram, and the electrical components for constructing an off-balance bridge for measuring the analog signal. We glued the transducers symmetrically on opposite faces of the free end of a narrow spring iron cantilever beam having an approximate width of 1 cm and length of 10 cm. The other end of the beam was clamped in a metal piece that could be plugged into a socket that exists on the top plate of the glider. A U-shaped piece was welded to the free end of this beam. Two small holes were drilled on this piece to hook the springs. The reflecting disk was mounted on the glider using a simple clamp arrangement that could be fitted to the base of the glider. The end posts for attaching the springs were made from an acrylic wedge machined to snap on to the air track. It is

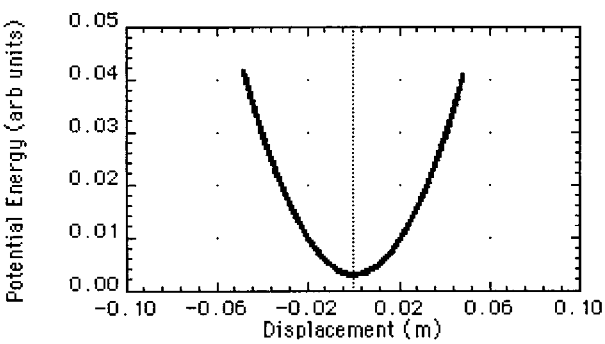

Fig. 2. Harmonic potential well for a spring oscillator on an air track. The solid line shows the potential-energy function obtained from distance measurements of an oscillator on an air track.

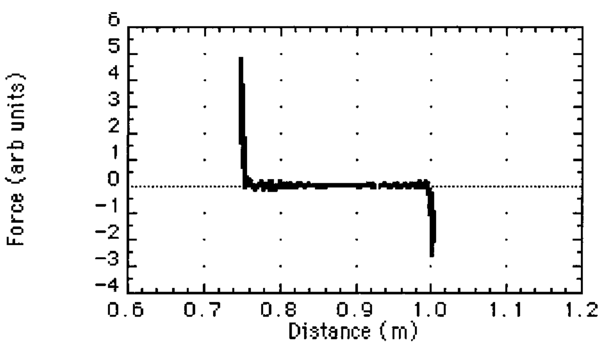

Fig. 4. Force-distance graph for a cart bouncing off springy blocks at the ends of the track.

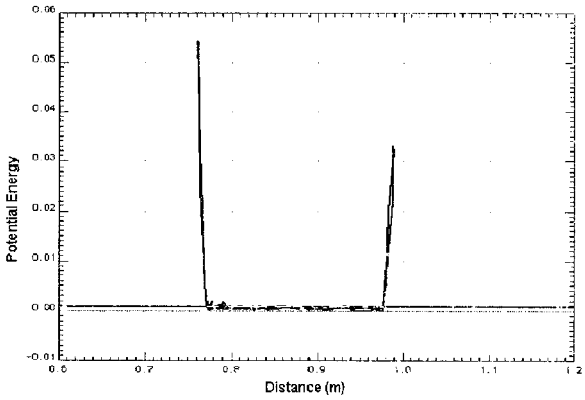

Fig. 5. Square well potential diagram for the cart bouncing off springy blocks at the ends of the track.

important to check that the addition of this hardware does not place the glider off balance or block the flow of air.

An important advantage of fabricating this force sensor has been that the leads of the electrical circuit could be made from extremely light and flexible connecting wire. We suspended this wire from a tall clamp to keep it from rubbing against the surface of the laboratory table. This arrangement overcomes the problems posed by the thick short cable that leads the signal from the manufacturer assembled student force sensor to the computer interface. This cable rubbing against the table introduces much of the friction in the dynamic cart.

Harmonic potential well: The data acquisition software records the distance of the cart from the position of the motion detector. A simple transformation using the data manipulation facilities of the software converts this measurement to a displacement about the equilibrium position of the cart. The program also automatically computes the velocities from the raw position data. The students view the displacement-time and force-time graphs and correlate these results with the on-line plots of force-displacement and velocity-displacement curves.

These data are then used to construct the potential energy diagram by using one of several options.

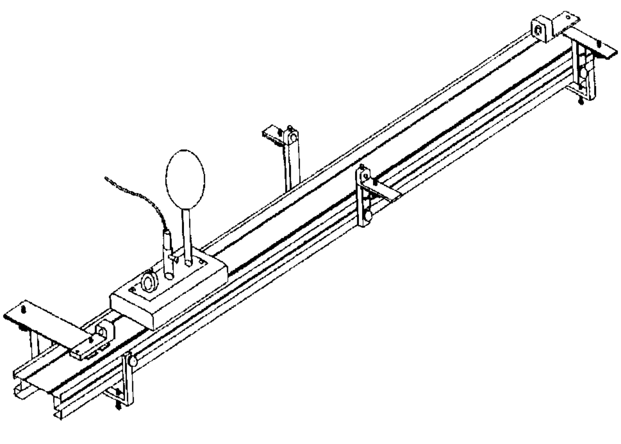

Fig. 6. Mechanical setup for recording the interaction of a rider magnet on a dynamic cart moving through a configuration of field magnets arranged along a track.

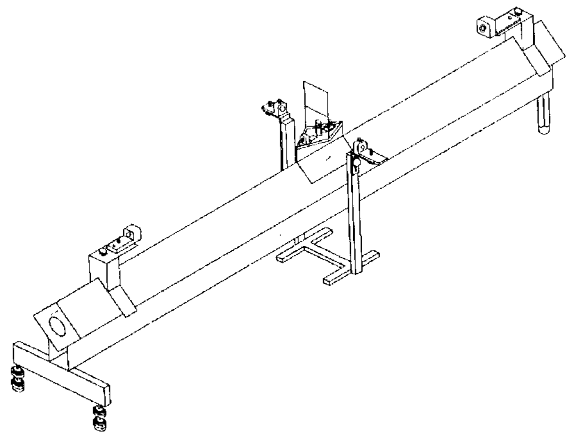

Fig. 7. Mechanical setup for recording the interaction of a rider magnet on a glider moving through a configuration of field magnets arranged along an air track.

(1) Assuming conservation of energy, the program can be used to compute the kinetic energy as the derived quantity $KE=\frac{1}{2}mv^2$ and the potential energy as $PE=TE-KE$.
(2) The students can fit a linear least-squares line to the force-displacement graph, relate the slope of the line to the effective spring constant k, and then compute the potential energy as $PE=\frac{1}{2}kx^2$.
(3) The potential energy can be found by superposing a grid on the force-displacement graph and estimating the area under the curve.

Figure 2 displays the potential-energy function obtained from distance measurements of an oscillator on an air track. The best quadratic fit is superposed as the solid line; the spread in the potential-energy values indicates the extent of the inevitable energy losses and the limits of validity of the assumption of conservation of energy.

2. Bouncing off springy walls

An important quantum mechanical system is a free particle bound in an energy well. A simple analog model of this situation is provided by a cart rolling freely along the track and bouncing off springy blocks placed at the edges (Fig. 3).

The basic arrangement is the same as for the case of the spring oscillator except that the springs are disconnected and springy blocks are fixed to the end posts with Velcro.™ We have variously used a sponge with a thin cardboard square glued to its faces, a blackboard eraser, and other soft materials of varying coefficients of restitution. For the dynamics cart, a double-faced, hammer-like plastic plunger (inset, Fig. 3) was designed to fit into the hooks of the student force sensor to generate a neat signal on impact with the end blocks on either side.

Square-well potential: Figure 4 displays the force versus distance graph for the bouncing at the edges of the track. The students interpret these graphs qualitatively, relating the sudden changes in velocity to the force experienced at the walls of the well. The corresponding potential-energy diagram, obtained by smoothing the velocity data to eliminate noise, is given in Fig. 5. By comparing this graph with the harmonic well curve and considering the difference in the motion of

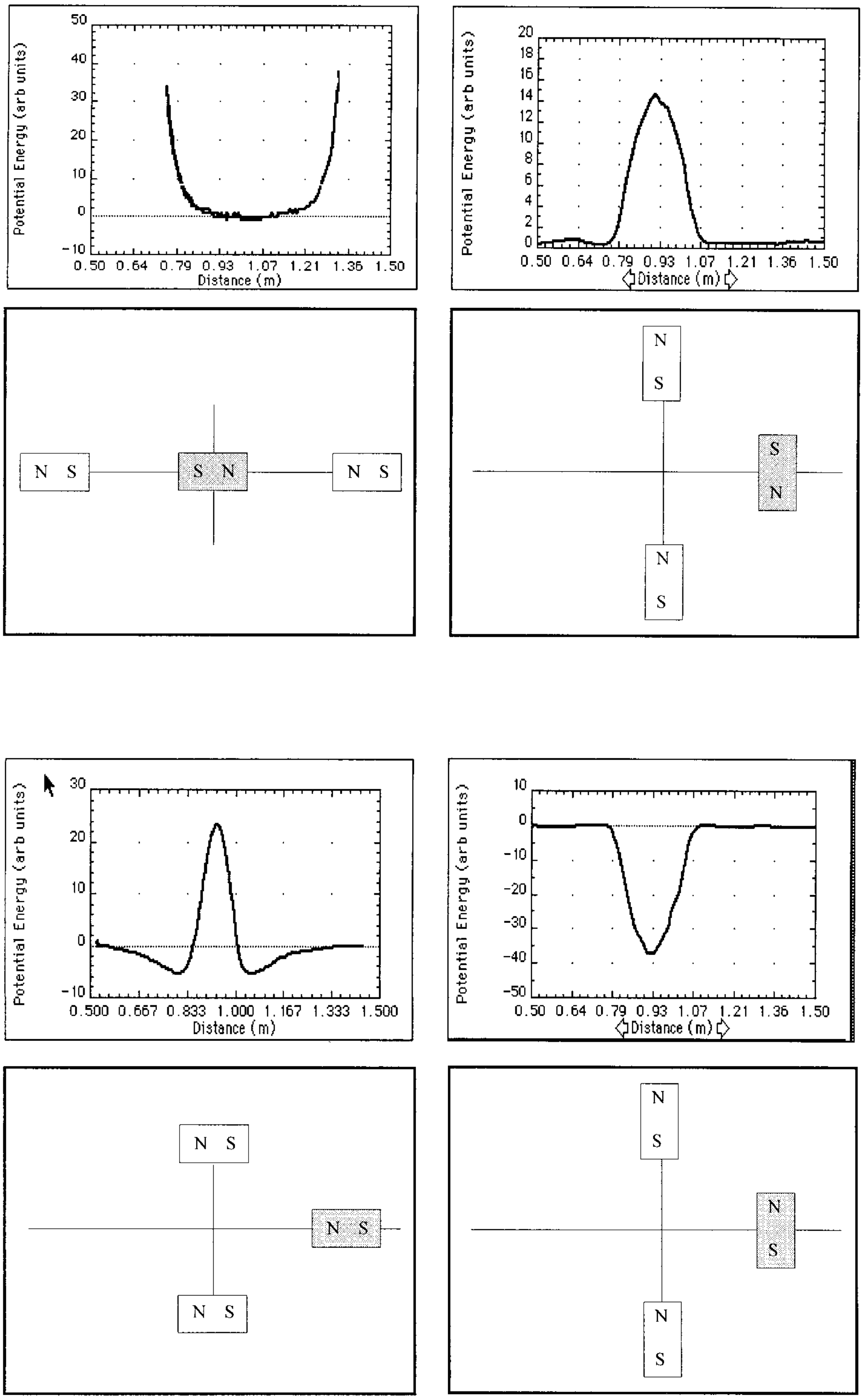

Fig. 8. Potential-energy diagrams. Direct measurement using a magnetic field sensor as a rider magnet (gray) moves on a track interacting with a configuration of field magnets.

the object in the two cases, the students gain an understanding of how the shape of the potential well is indicative of the operative forces.

B. Magnetic interactions

Some important potential shapes can be generated by the combined effect of magnets placed in attractive and repulsive modes along the track and interacting with an object moving along the track carrying a magnet. The interaction at a distance has an important advantage over the contact interactions, which often have too much damping to allow the assumption of energy conservation even over a short duration.

In principle, the measurement of position using the motion detector in real time allows a straightforward method of

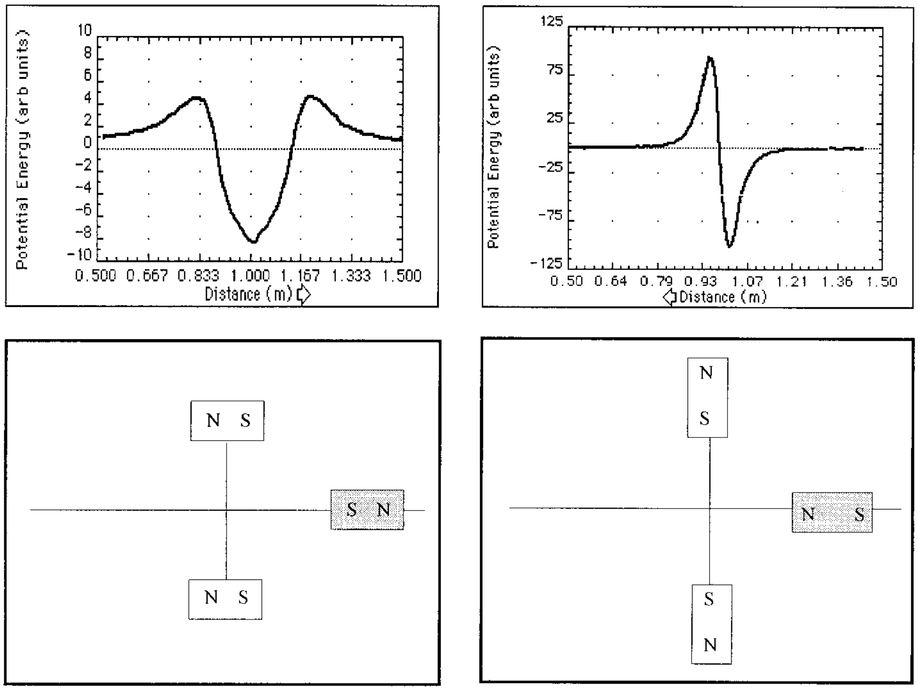

Fig. 8 (*Continued.*)

computing the velocity and hence the kinetic and potential-energy functions for a nearly conservative system. In practice, even the slightest noise in the signal can lead to large jitters in the values of velocity and render this procedure useless. In a bid to circumvent this problem, we have used a magnetic field sensor,[9] which incorporates a Hall effect transducer, to generate directly the potential-energy diagrams for one-dimensional motion. This sensor is mounted on the cart or the glider, and as it moves through a configuration of magnets, the magnetic intensity is recorded as a function of distance. Since for a magnetic dipole placed in an external magnetic field of intensity B_x along the x direction, the net force experienced along the x direction is given by

$$F_x = -q_m l \frac{\partial B_x}{\partial x},$$

where $q_m l$ is the strength of the dipole, the potential energy

$$U(x) = -\int_0^x F_x dx = q_m l B_x$$

is simply proportional to the magnetic field intensity B_x. Thus the measurement gives a direct on-line plot of the potential energy as a function of distance. The method offers a great deal of experimental simplification and permits an investigation of several potential shapes in a short duration class.

Dynamics cart system: Figure 6 gives a schematic diagram of the mechanical arrangement. We have used Neodymium magnets supplied by PASCO.[10] These magnets have a large magnetic moment and need to be used with due care. The magnets are held along or across the track at a fixed height using specially designed mounting platforms that slide into the edges of the track. The field magnet can slide along a slot in the platform and can be fixed with any orientation in a horizontal plane parallel to that of the track. These degrees of freedom allow, (i) changing the strength of the magnetic interaction by varying the distance of the field magnet from the edge of the track, and (ii) changing the nature of interaction by rotating the axis of the magnet relative to that of the rider magnet. The clamping screws prevent the magnets from flying out under the influence of strong interactions. A flat plate screwed on the cart has a holder slot for sliding in the Hall probe tube casing. The rider magnet is fixed on this plate with Velcro™. Again, the plate carries a post for attaching the reflector disk.

Air-track system: The basic arrangement using the air track remains unchanged from the one for the dynamics cart. In this case, too, we have fabricated and used specially designed accessory pieces to hold the magnets along and across the track (Fig. 7). The Hall probe is mounted on the glider using a simple holder that plugs into the central hole on the top plate of the glider. To decrease added mass, we reduced the length of the acrylic tube holding the sensor to about 5 cm and also replaced the thick output cable by thin flexible wires.

A good way of eliminating wobbling and unnecessary torque is to use symmetrical planar arrangements of magnets around the axis of motion, ensuring that the additional mass of the glider does not cause the center of mass to shift from the axis of the track.

C. Potential-well diagrams

The actual measurement of the magnetic intensity using the Hall probe is quite simple. Figure 8 displays a few illustrative configurations of the rider and field magnets and the corresponding potential-energy diagrams generated through actual experiments. In these graphs, we have defined the potential energy in regions far from the positions of the magnets as zero and accordingly used the corresponding constant Hall probe reading to offset the measured values.

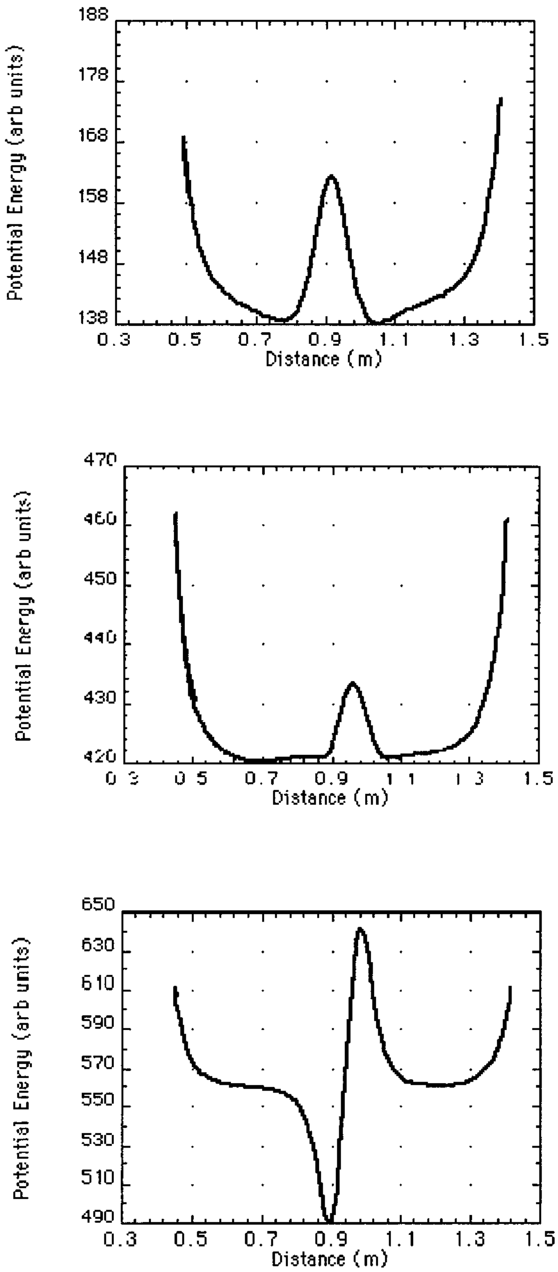

Fig. 9. Students are asked to create magnet arrangements to create potentials such as these wells.

For each of these potentials, students obtain an interesting result by starting the cart moving with different velocities. Then, they see variations in the change in motion, regions where the cart is able to travel, and the regions where it gets trapped and executes local oscillations. The students may also slide the cart gently across the region of interaction and retrace the potential-energy curve. Relating the speed that must be imparted to the cart to cross a particular barrier or potential shape gives a kinesthetic experience of how an object moves in a potential well.

III. THE LEARNING PATH

These experiments have been incorporated into the laboratory activities accompanying a conceptual course for future elementary school teachers[11,12] and a modern physics course

Table I. Student response to the questionnaire seeking their assessment of the potential-energy diagram activity.

	Scale	1	2	3	4	5
		Not effective			Effective	
Q	Question					
1	Collecting data with the computer	1	6	10	14	16
2	Setting up the experiments	2	2	10	22	10
3	Looking at potential-energy versus distance graphs	1	7	11	20	8
4	Comparing the motion and potential-energy diagrams	2	3	13	18	9
5	Performing graphing and descriptions in writing	1	7	9	23	6
6	Answering the questions on the worksheet	1	1	14	27	4
7	Discussions with the group members	1	0	3	16	25
8	The potential-energy activity in general	3	1	12	21	8
		Difficult				Easy
9	Difficulty level of using the hardware/software	1	10	11	19	5

for future secondary teachers at Kansas State University. We developed an activity sheet to guide students along the desired learning path. During the early stages of the lesson the emphasis is on exploration of the experimental system and qualitatively describing the motion of the cart. Students are asked to indicate where the cart is moving relatively fast, relatively slowly, and where, if any place, the velocity is zero. The students evaluate the kinetic and potential energy at each point along the path of the object, look at how the force varies as a function of position, plot the potential-energy diagrams, and interpret the shape of the energy well to predict the motion of the cart under varying initial conditions. Then, they construct a variety of potential shapes using different configurations of magnets. With the Hall probe, they generate on-line graphs of the potential-energy diagrams. The potential diagram is then used as a representation of some unknown interaction. The students explore how an object will behave in this potential. On the basis of the given picture, they try to predict the motion under different initial conditions and proceed to empirically verify their hypothesis and expectations. The arrangement allows us to pose open-ended problems wherein the students are asked to configure the magnets so as to create a potential in which an object can be trapped in a certain region or have some other specified motion. Pondering over motion in potential-energy diagrams such as those in Fig. 9 provides a casual introduction to idealized models of particle interactions that the students will encounter in quantum physics.

Student response: In Fall 1995, 47 students completed the unit as an extra-credit activity. A questionnaire administered immediately afterwards, asked the students to describe their view of the effectiveness of these novel experiments. Table I lists the questions asked and the student response on a Likert scale of 1–5. Figure 10 summarizes these data graphically as a histogram for the two key questions, namely, the effectiveness of looking at potential energy versus distance graphs (Q3) and comparing the motion and the potential-energy dia-

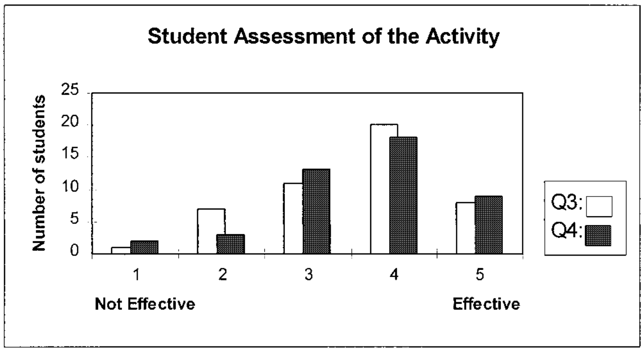

Fig. 10. Effectiveness of looking at the potential-energy versus distance graphs and comparing these with the motion of the cart.

grams (Q4). These data corroborate the observed enthusiasm of the students toward the hands-on activity and their perception of its usefulness.

IV. CONCLUSIONS

These experiments and the accompanying material have been field tested in the classroom over two successive semesters of instruction. The student response and feedback from classroom usage has been consistently positive. The real time capture of data and immediate processing makes it easy for the students to relate how different physical quantities change as a function of displacement. The sequence of experiments builds the bridge from tangible forces exerted by springy blocks to more complicated force fields exerted by a configuration of magnets. It systematically leads the students from a concrete experience of forces in real physical systems to the abstract representation of their effect in potential-energy diagrams. It allows them to move from specific experiments to general conclusions. We hope that this pedagogic route will prepare the students to extend the potential-energy diagram concept to models of interactions in quantum physics.

The experiments described in this paper can be used at various instructional levels either as laboratory activities added to the traditional mechanics course or as a preamble to a quantum mechanics course. The emphasis can be either on the data capture and rigorous analysis to obtain potential-energy functions from the force of interaction, or it can be on generating on-line pictures of potential-energy diagrams and qualitative interpretation of motion of an interacting object.

A deliberate attempt has been made to use devices that are readily available from commercial suppliers. For a robust classroom arrangement, however, we found it convenient to fabricate additional accessory pieces. We have included a functional description of these in the paper.

ACKNOWLEDGMENTS

We are grateful to Richard Zotti for his help with the design and fabrication of the accessories used in this work and to Shauna Schauf-Allen for the schematic diagrams. One of us (PJ) would like to thank the American Physical Society and other sponsors for the grant of the Kilambi Ramavataram Fellowship which enabled her to work with the Physics Education Research Group at KSU during Fall 1995. She also thanks the Fulbright Foundation for the Tata–Fulbright Travel award. This work was supported, in part, by the National Science Foundation under Grant ESI-945-27882.

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[5]S. G. Eckstein, ''Verification of fundamental principles of mechanics in the computerized student laboratory,'' Am. J. Phys. **58**, 909–915 (1990).
[6]Universal Lab Interface; Program MOTION, Version 4.5, Motion detector (U-MD); Student Force Sensor (Code SFS-DIN), Vernier Software.
[7]Dynamics System (ME-9249A), Air track (SF-9214), and assorted accessories, PASCO Scientific.
[8]Strain Gauge Force Sensor Kit (SGK-DIN), Vernier Software.
[9]Magnetic field sensor (Code MG-DIN), Vernier Software.
[10]Neodymium Magnets (EM-8621), PASCO scientific.
[11]Dean Zollman, ''Learning Cycles in a Large Enrollment Class,'' Phys. Teach. **28**, 20–25 (1990).
[12]Dean Zollman, ''Preparing Future Science Teachers: The Physics Component of a New Programme,'' Phys. Ed. **29**, 271–275 (1994).

PURE COWARDICE

When Dirac published his relativistic equation for the electron in 1928, he opened the way for the discovery of quantum electrodynamics, which followed soon afterwards. The interpretation of the Dirac equation pointed to the necessity of the positron, but initially Dirac did not actually predict the existence of that particle. Instead, he indicated that somehow the expected positively charged object might be identified with the proton, which was well known experimentally but is almost two thousand times heavier than the electron (from which it differs in other important ways as well). When I asked him, many decades later, why he had not immediately predicted the positron, Dirac replied in his usual pithy manner, ''Pure cowardice.''

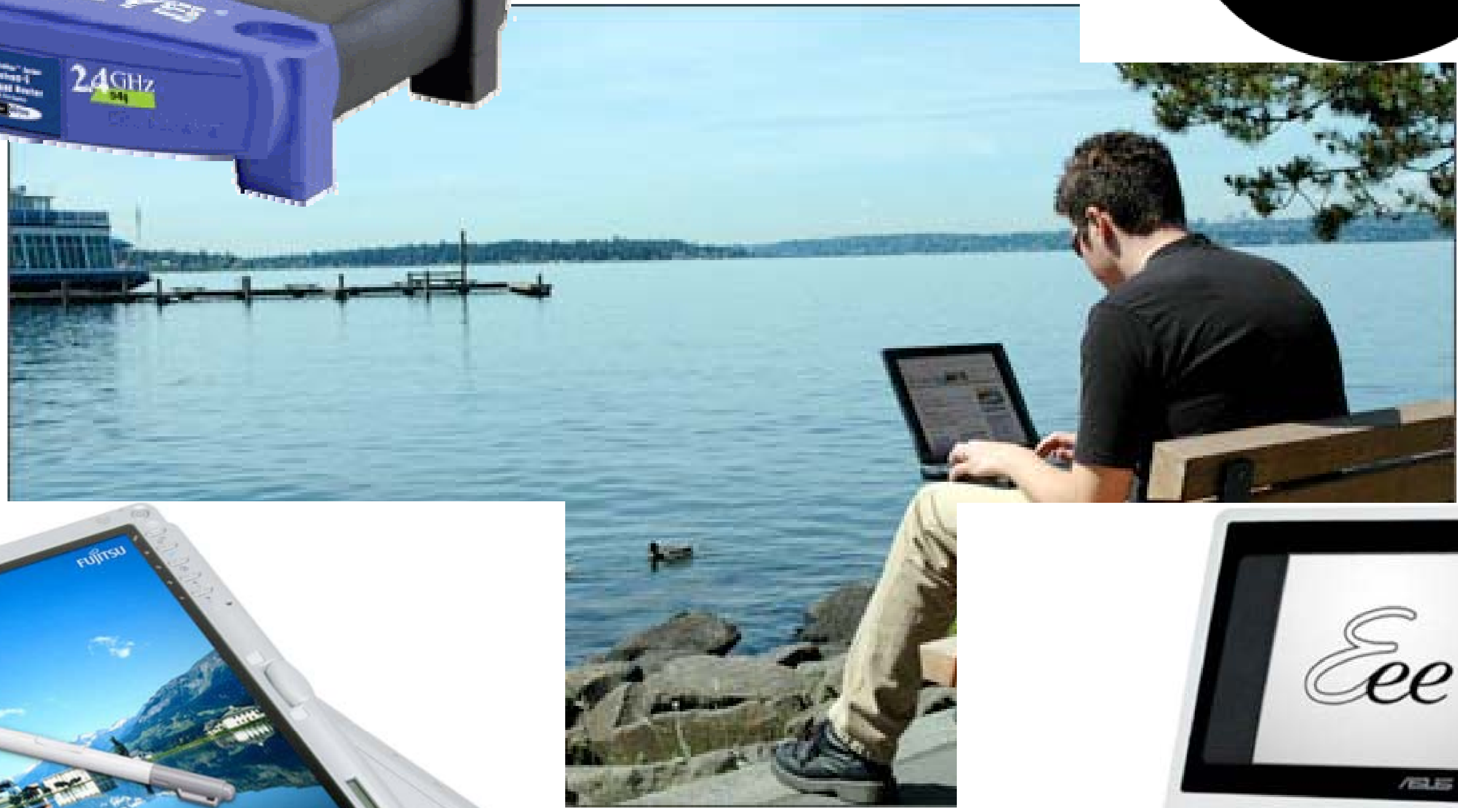
Murray Gell-Mann, *The Quark and the Jaguar: Adventures in the Simple and the Complex* (W. H. Freeman and Company, New York, 1994), p. 179.

Wide-Area WiFi Basics

2009 ICTP School on
Low-Cost Wireless Solutions in
Developing Countries:
Best Practices

The Abdus Salam
International Centre
for Theoretical Physics


LINKSYS
2.4GHz




FUJITSU


Eee PC

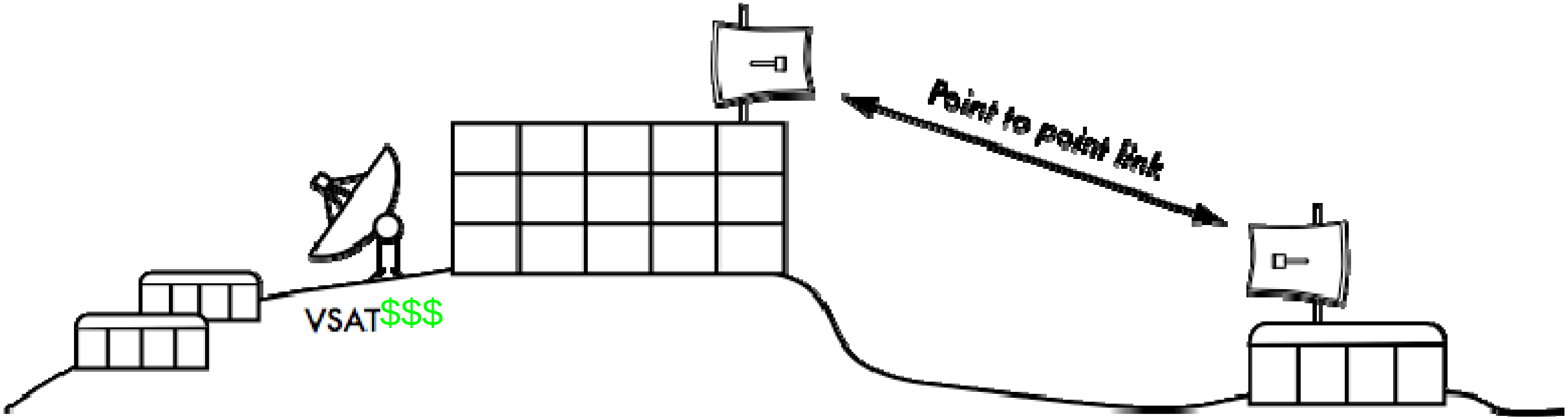
Wireless networking protocols

The 802.11 family of radio protocols are commonly referred to as WiFi.

- ***802.11a*** supports up to 54 Mbps using the 5 GHz ISM and UNII bands.
- ***802.11b*** supports up to 11 Mbps using the 2.4 GHz ISM band.
- ***802.11g*** supports up to 54 Mbps using the 2.4 GHz ISM band.
- ***802.11n*** (draft) supports up to 300 Mbps using the 2.4 GHz and 5 GHz ISM and UNII bands.
- ***802.16*** (WiMAX) is not 802.11 WiFi! It is a much more complex technology that uses a variety of licensed and unlicensed frequencies.

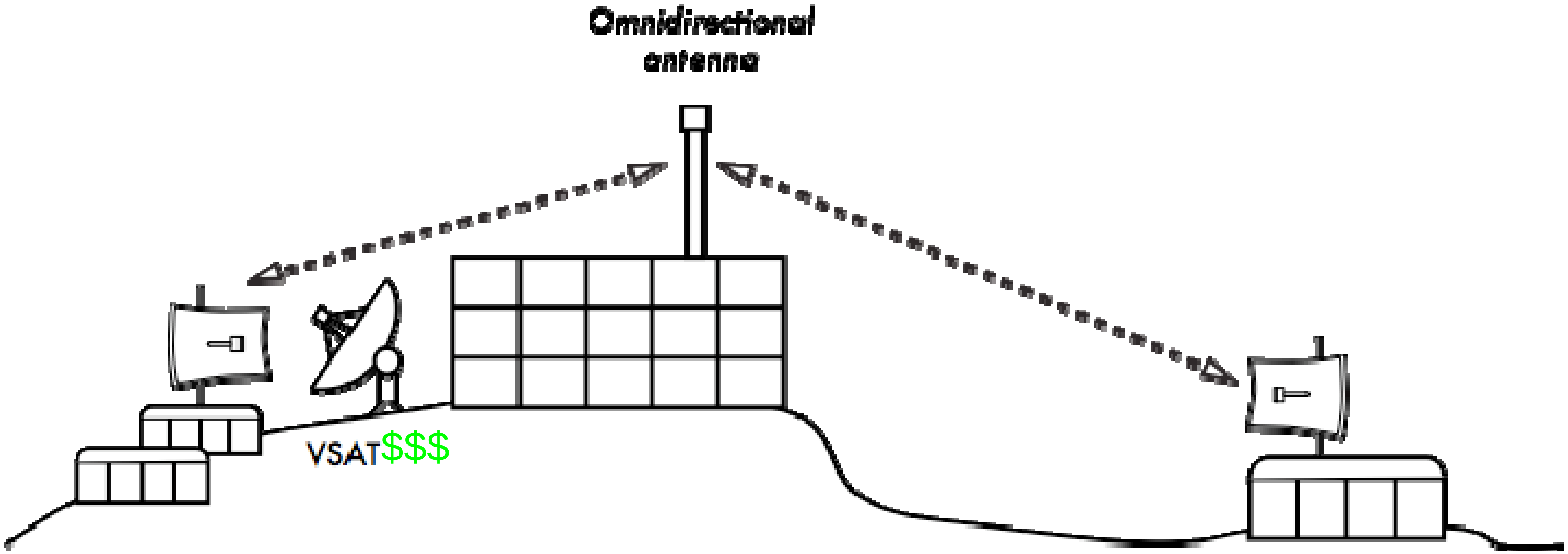
Point to Point

The simplest connection is the ***point-to-point*** link. These links can be used to extend a network over great distances.



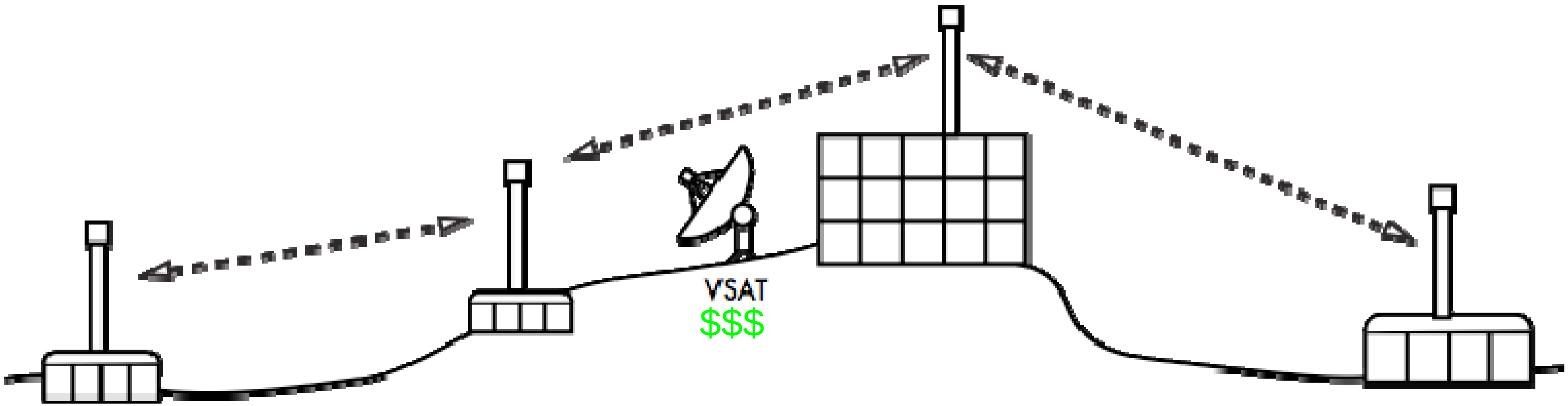
Point to Multipoint

When more than one computer communicates with a central point, this is a ***point-to-multipoint*** network.

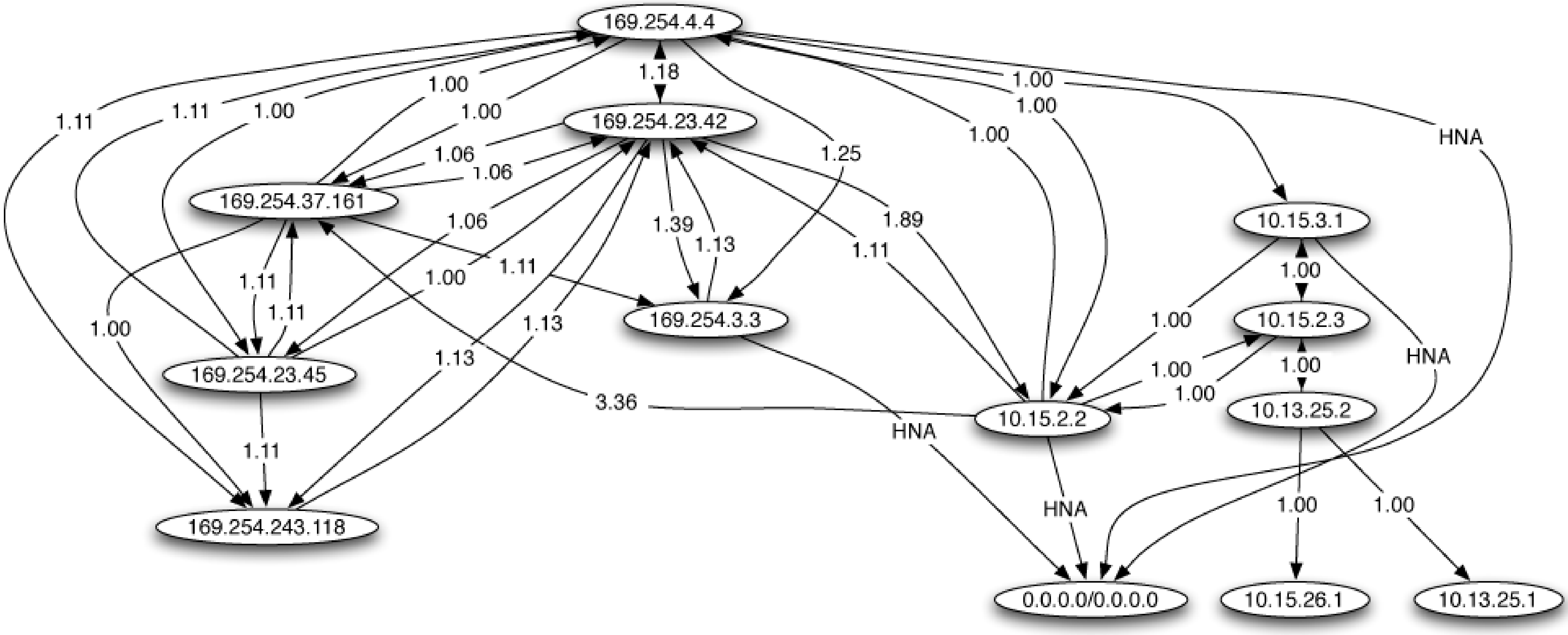


Multipoint to Multipoint

When any node of a network may communicate with any other, this is a ***multipoint-to-multipoint*** network (also known as an ***ad-hoc*** or ***mesh*** network)



Dynamic mesh



The “Hidden Node”

When two clients are in range of the same access point but not each other, their transmissions can interfere with each other. This condition is called a ***hidden node*** problem.

- Hidden node is alleviated somewhat by channel reservation (CTS/RTS) instead of relying on CSMASpecify a maximum packet size, above which CTS/RTS is usedCTS/RTS is not perfect, but can help at a cost of overall throughput.
- It is only possible when access points are used.

Timing Issues

Due to the very fast timing of 802.11 frames, speed of light becomes an issue at long distances. Propagation delays become very apparent!

At approximately 15 km, standard timings are too short for acknowledgements to be received.Some cards and drivers (such as Atheros) allow timings to be adjusted, permitting very long distance communications.

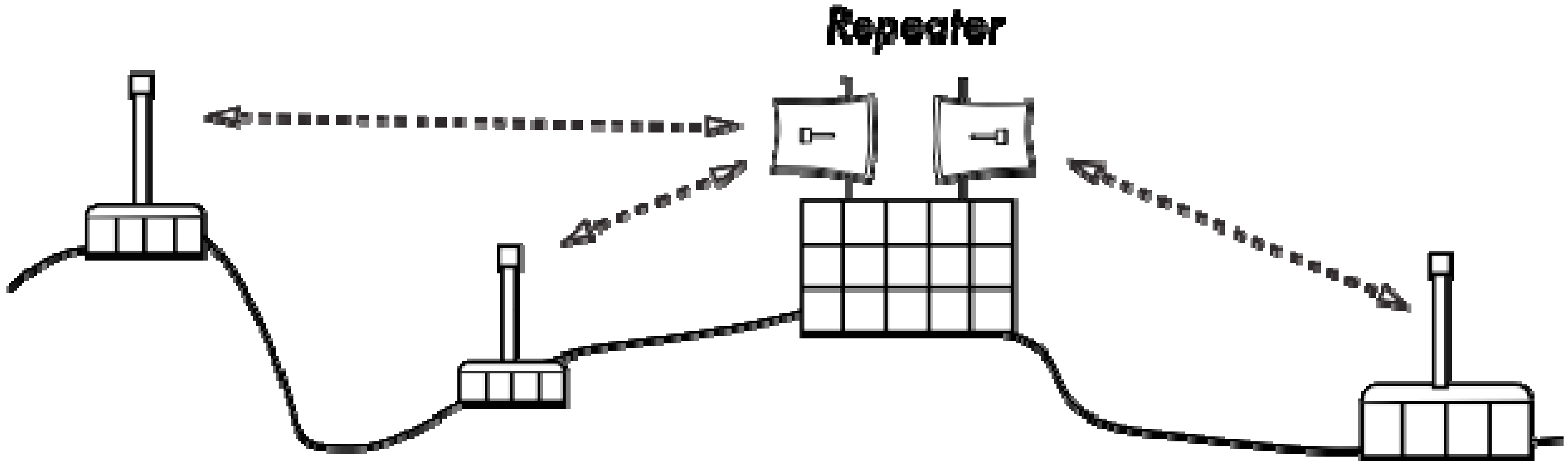
Proprietary protocols (such as Mikrotik Nstreme) use TDMA to avoid these ACK timing issues.

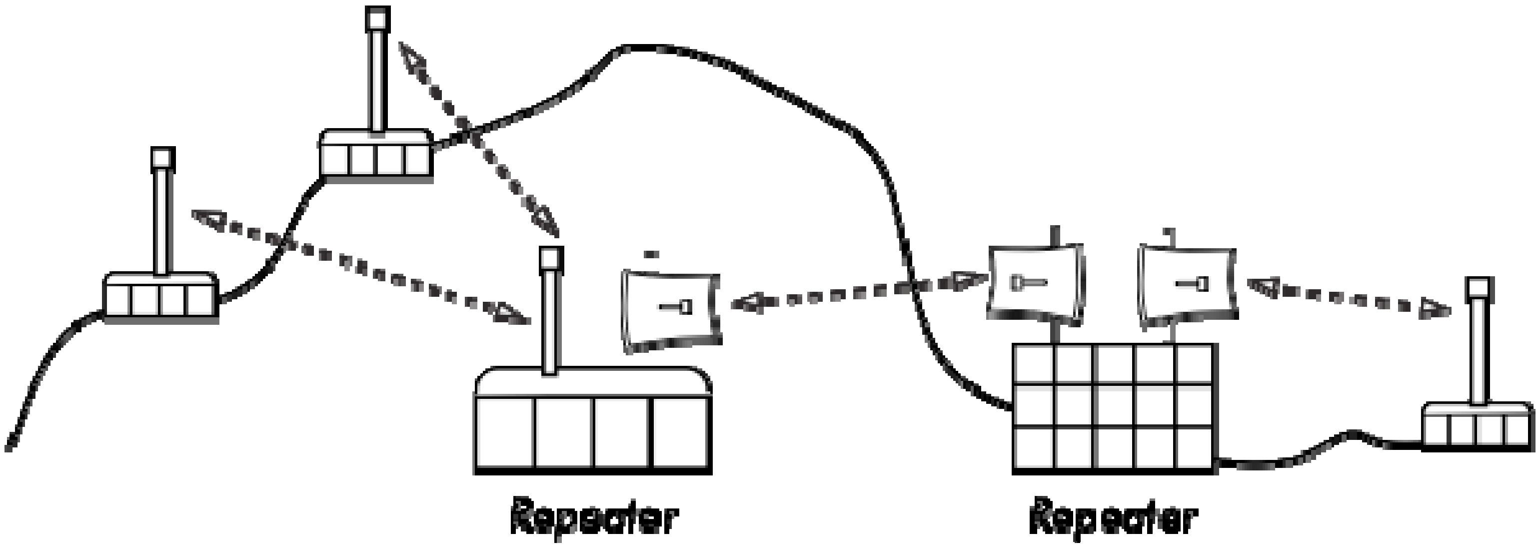
Practical distance limits

WiFi was not designed to travel further than a few hundred meters. With some minor modifications, this distance can be greatly increased.

- **Up to 300 meters**: Use off-the-shelf devices
- **Up to 15 km**: Add directional antennas
- **Up to 100 km**: Use open source or “long distance” equipment to change timing parameters
- **> 100 km**: Use proprietary TDMA protocols to avoid ACK timing problems

Repeaters



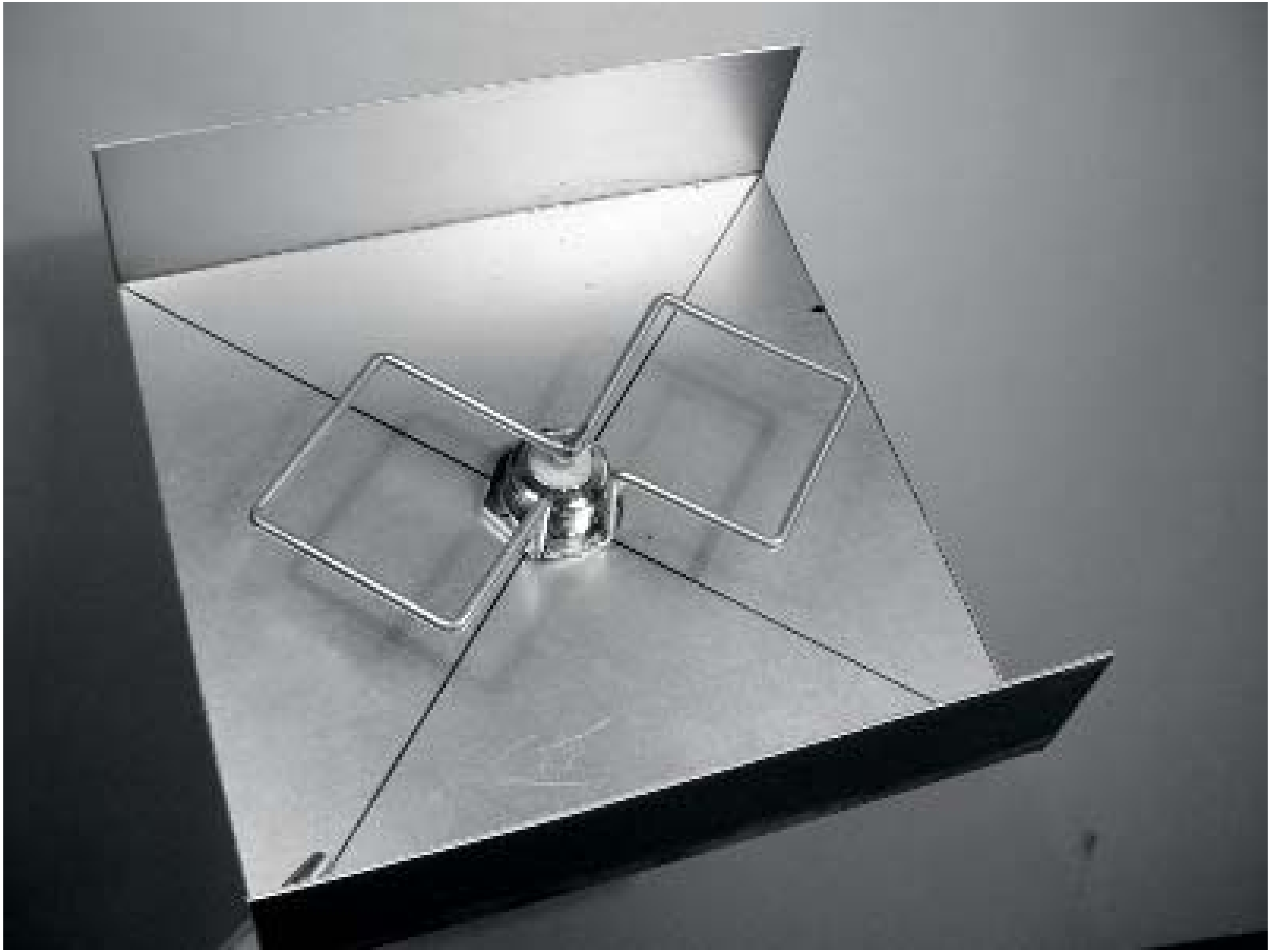


Simple Do-It-Yourself WiFi Antennas

1/4 wavelength ground plane

- Very easy to make
- Tiny!
- Approximately 2 to 4 dBi gain
- Useful for testing or indoor use

Biquad



Biquad used as dish feed

- More complex design
- About 11 dBi gain when used alone
- Can be tricky to build correctly, depending on available materials

- Versatile, with impressive gain in a small space27 to 31 dBi gain when used with a dish!

http://trevormarshall.com/biquad.htm

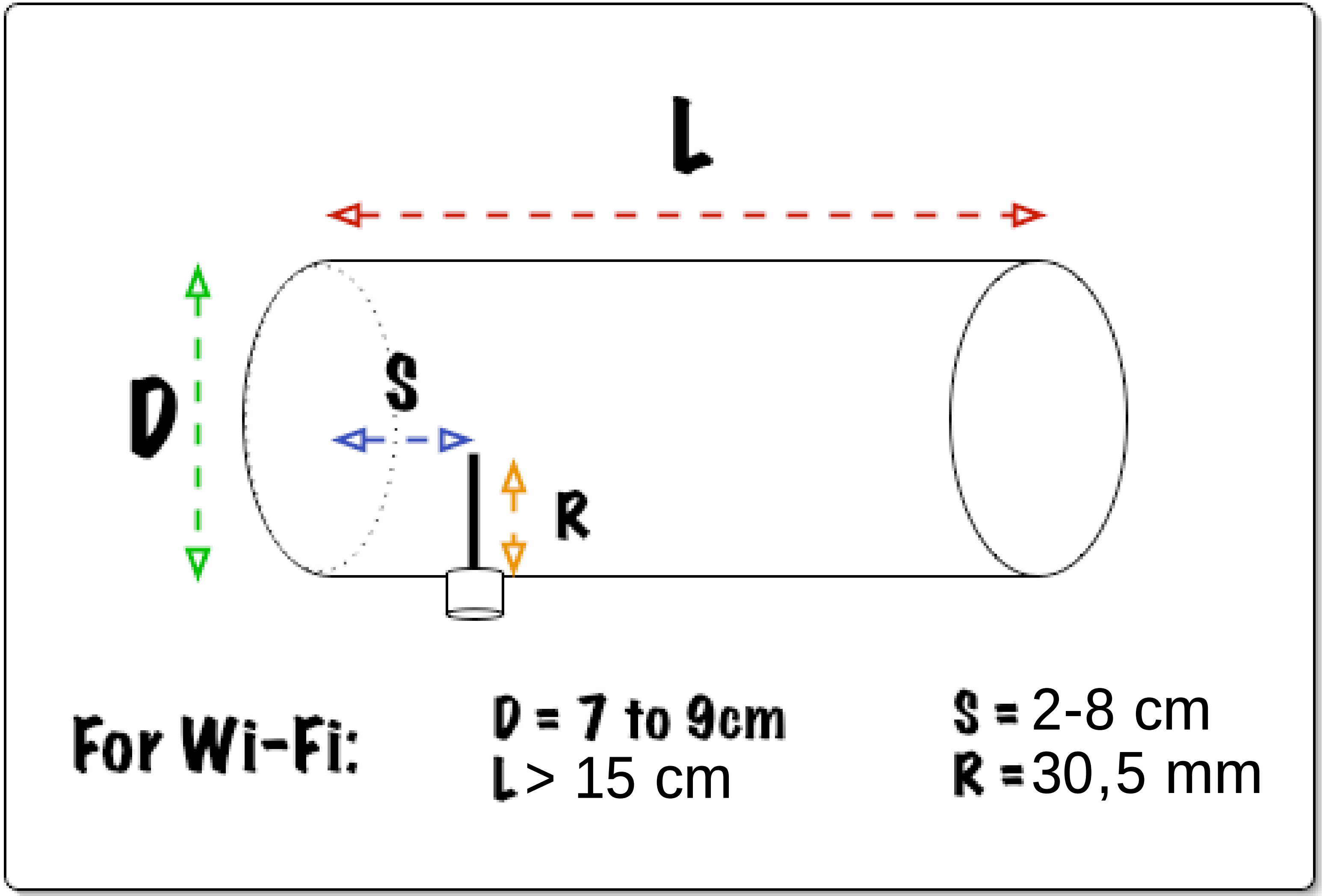
Very large parabolic

279+ kilometer links can be made!

The "cantenna"

http://www.turnpoint.net/wireless/has.html

Cantenna dimensions



Beef stew can

Cookies are popular

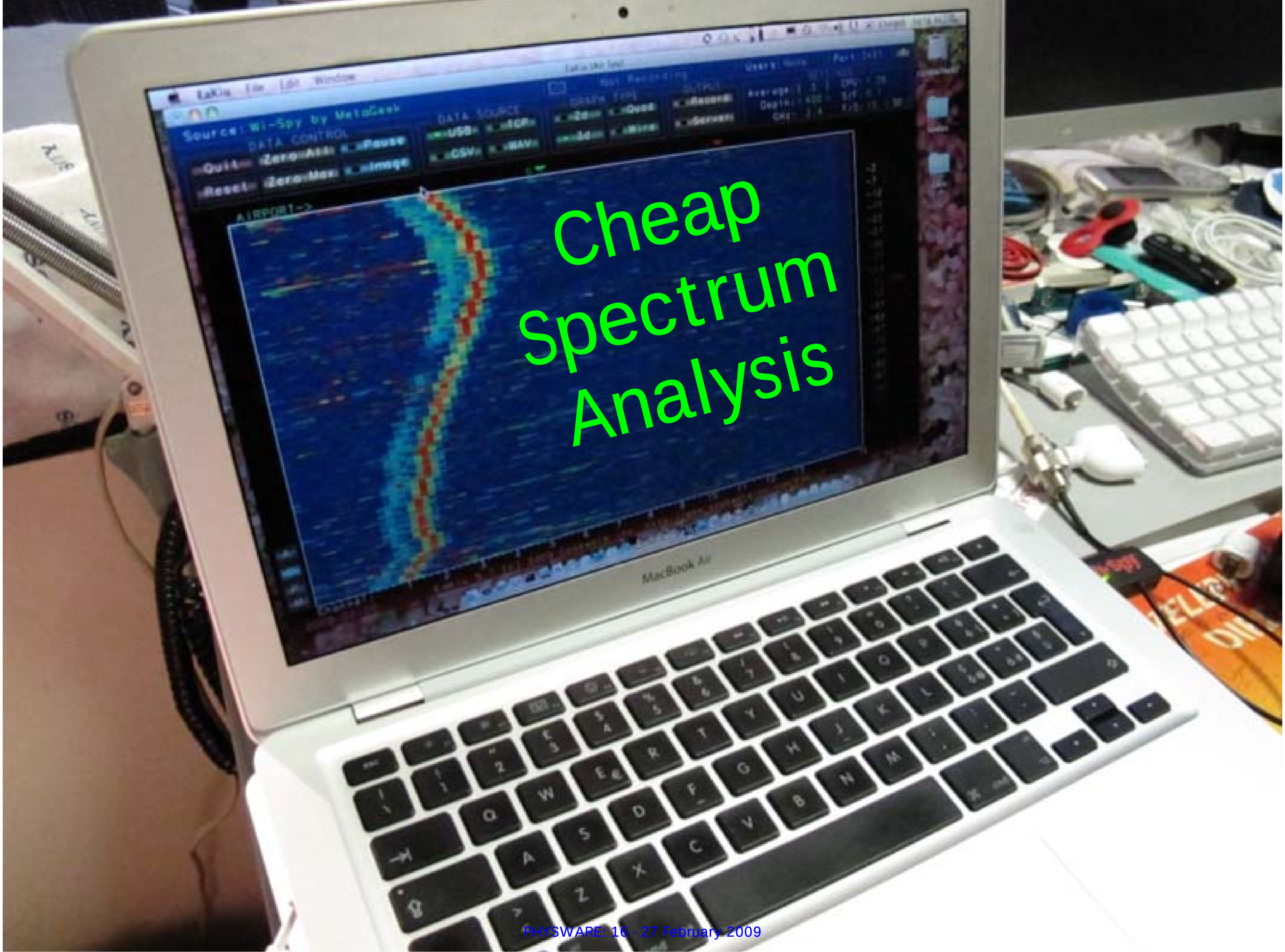
Use what you can find

Can as dish feed

- Possibly the simplest antenna design, assuming you can find an appropriate can
- Construction is very easy
- 10 to 14 dBi gain is typical, with approximately 60 degree beam width

30+ dBi gain is achievable when used as a feed for a parabolic dish

Cheap Spectrum Analysis

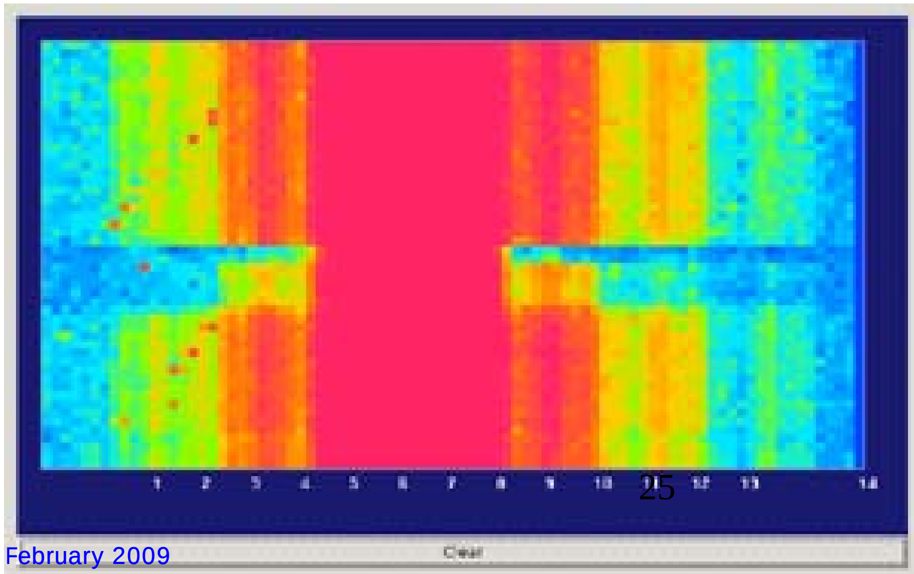


Spectrum Analyzer

A good spectrum analyzer is usually the best (and most expensive) tool for detecting sources of interference.

Wi-Spy spectrum analyzer

Wi-Spy network analyzer, *http://www.metageek.net/*



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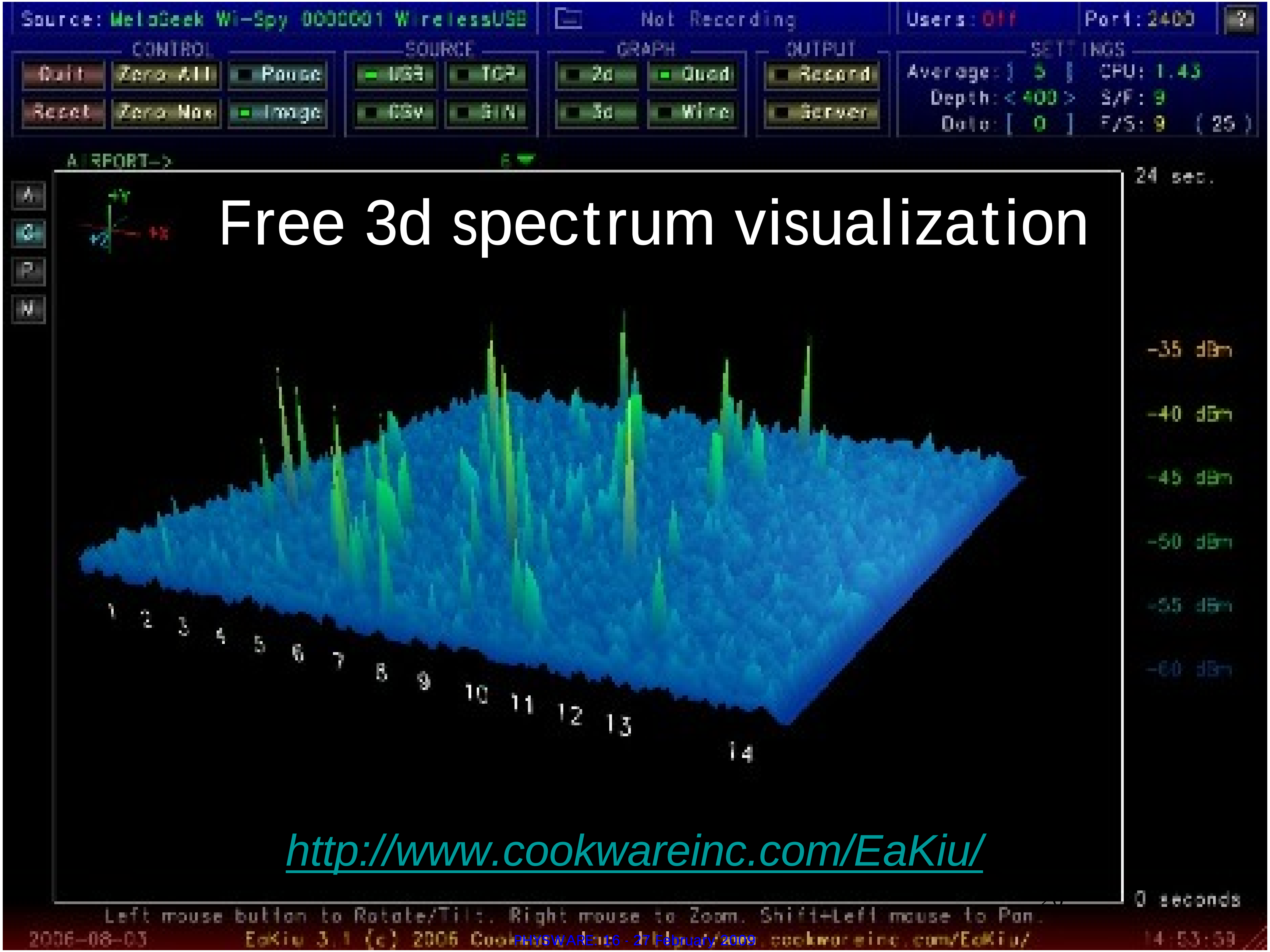
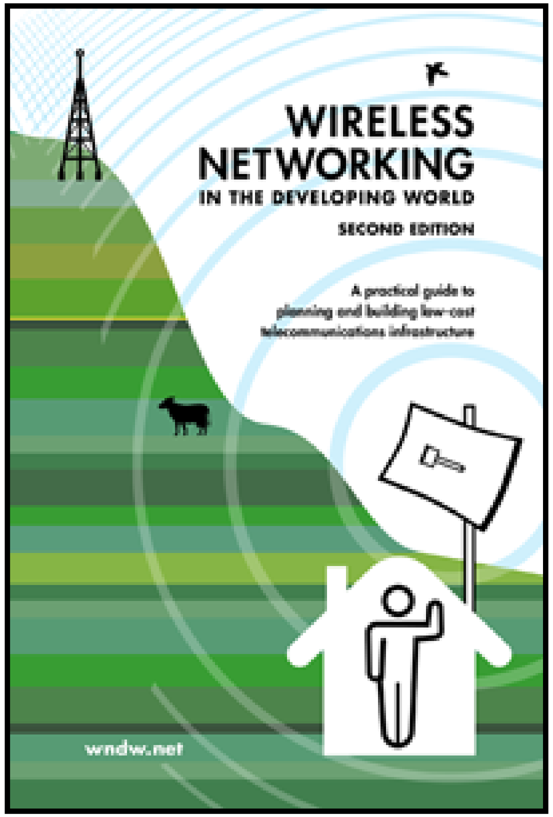
Free 3d spectrum visualization



http://www.cookwareinc.com/EaKiu/

Live Demo

Watch the effect of these radio sources in real time.



Portions of this talk were adapted from the free book **Wireless Networking in the Developing World**, *http://wndw.net/*

Wireless Sensor Networks: an introduction

Marco Zennaro
The Abdus Salam International Centre
for Theoretical Physics
Trieste, Italy

Infrastructure-based wireless networks

- Typical wireless network: Based on **infrastructure**
- E.g., GSM, UMTS, WiFi, …
- Base stations connected to a wired backbone network
- Mobile entities communicate wirelessly to these base stations
- Traffic between different mobile entities is relayed by base stations and wired backbone
- Mobility is supported by switching from one base station to another
- Backbone infrastructure required for administrative tasks

Infrastructure-based wireless networks

- What if …
- No infrastructure is available? – E.g., in remote areas
- It is too expensive/inconvenient to set up? – E.g., in remote sites
- There is no time to set it up? – E.g., in disaster relief operations

- Try to construct a network without infrastructure, using networking abilities of the participants
- This is an **ad hoc network** – a network constructed "for a special purpose"
- Simplest example: Laptops in a conference room – a single-hop ad hoc network

Problems/challenges for ad hoc networks

- Without a central infrastructure, things become much more difficult!
- Problems are due to
  - Lack of central entity for organization available
  - Limited range of wireless communication
  - Mobility of participants
  - Battery-operated entities

- Without a central entity (like a base station), participants must organize themselves into a network (**self-organization**)

Wireless sensor networks

- Participants in the previous examples were devices close to a human user, interacting with humans

- Alternative concept:
- Instead of focusing interaction on humans, **focus on interacting with environment**
- Network is embedded in environment
- Nodes in the network are equipped with sensing and actuation to measure/influence environment
- Nodes process information and communicate it wirelessly

Wireless sensor networks

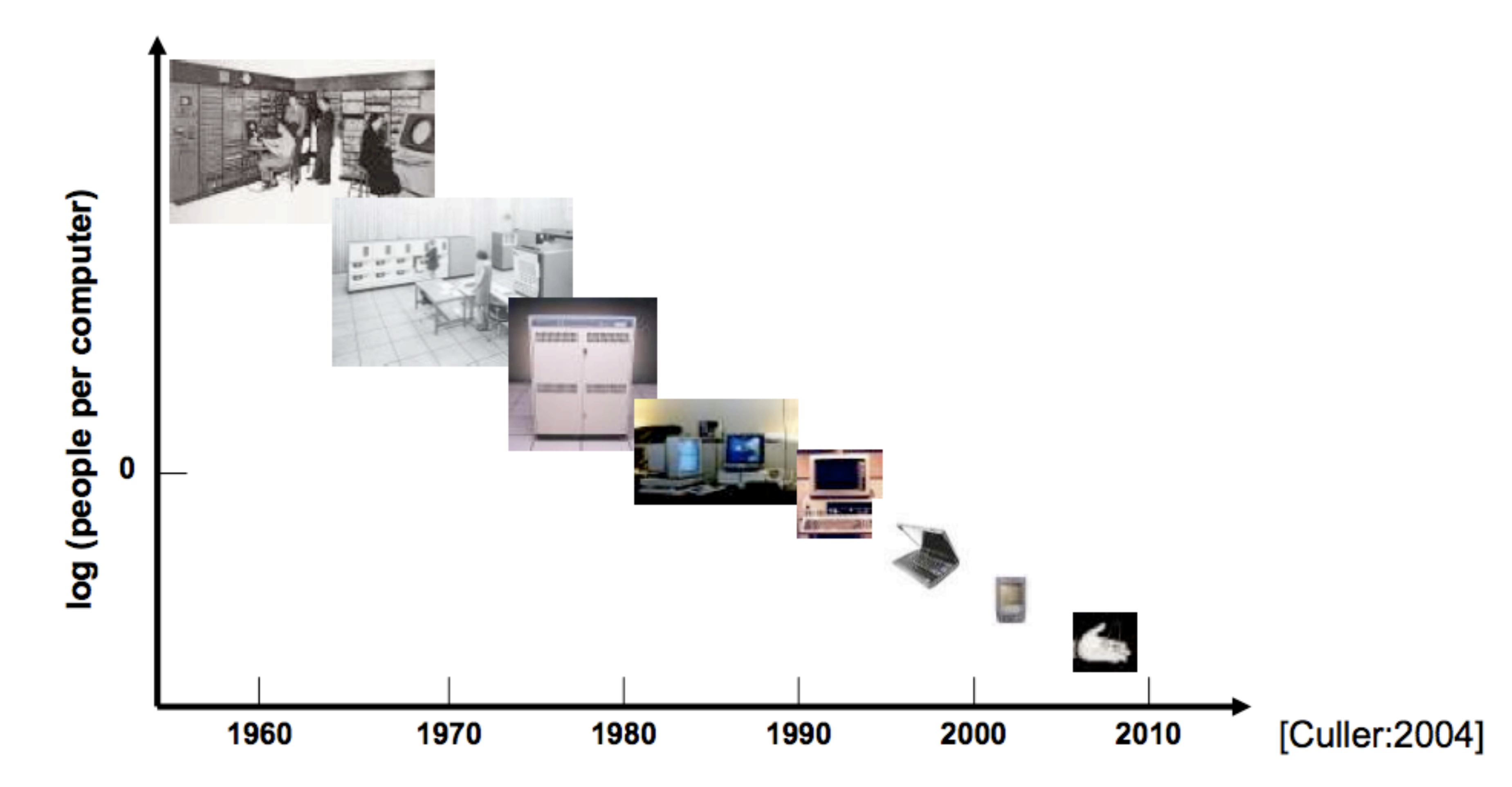
- A Wireless Sensor Network is a **self-configuring** network of small sensor nodes communicating among themselves using **radio signals**, and deployed in quantity to sense, monitor and understand the physical world.

- Wireless Sensor nodes are called **motes.**

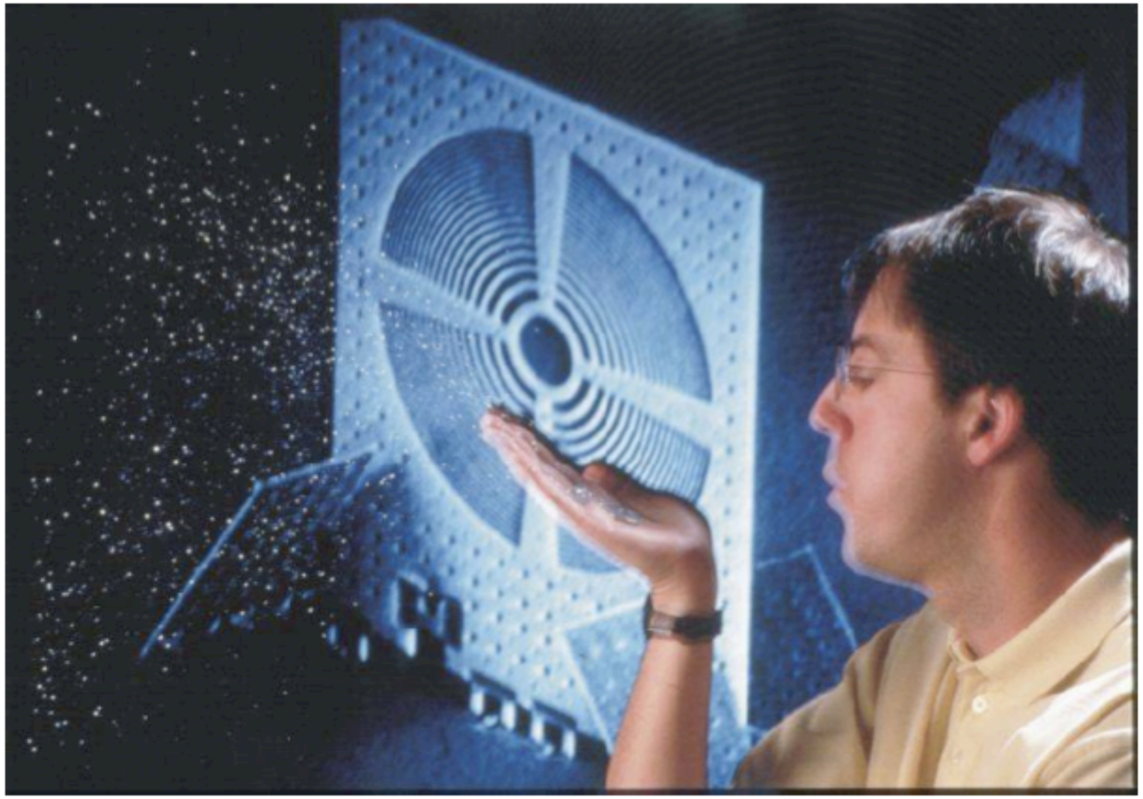
Wireless sensor networks

- WSN provide a bridge between the real physical and virtual worlds.
- Allow the ability to observe the previously unobservable at a fine resolution over large **spatio-temporal scales.**
- Have a wide range of potential applications to industry, science, transportation, civil infrastructure, and security.

Wireless sensor networks



Wireless sensor networks



Next Century Challenges: Mobile Networking for "**Smart Dust**"

J. M. Kahn,
R. H. Katz,
K. S. J. Pister

(MobiCom 1999)

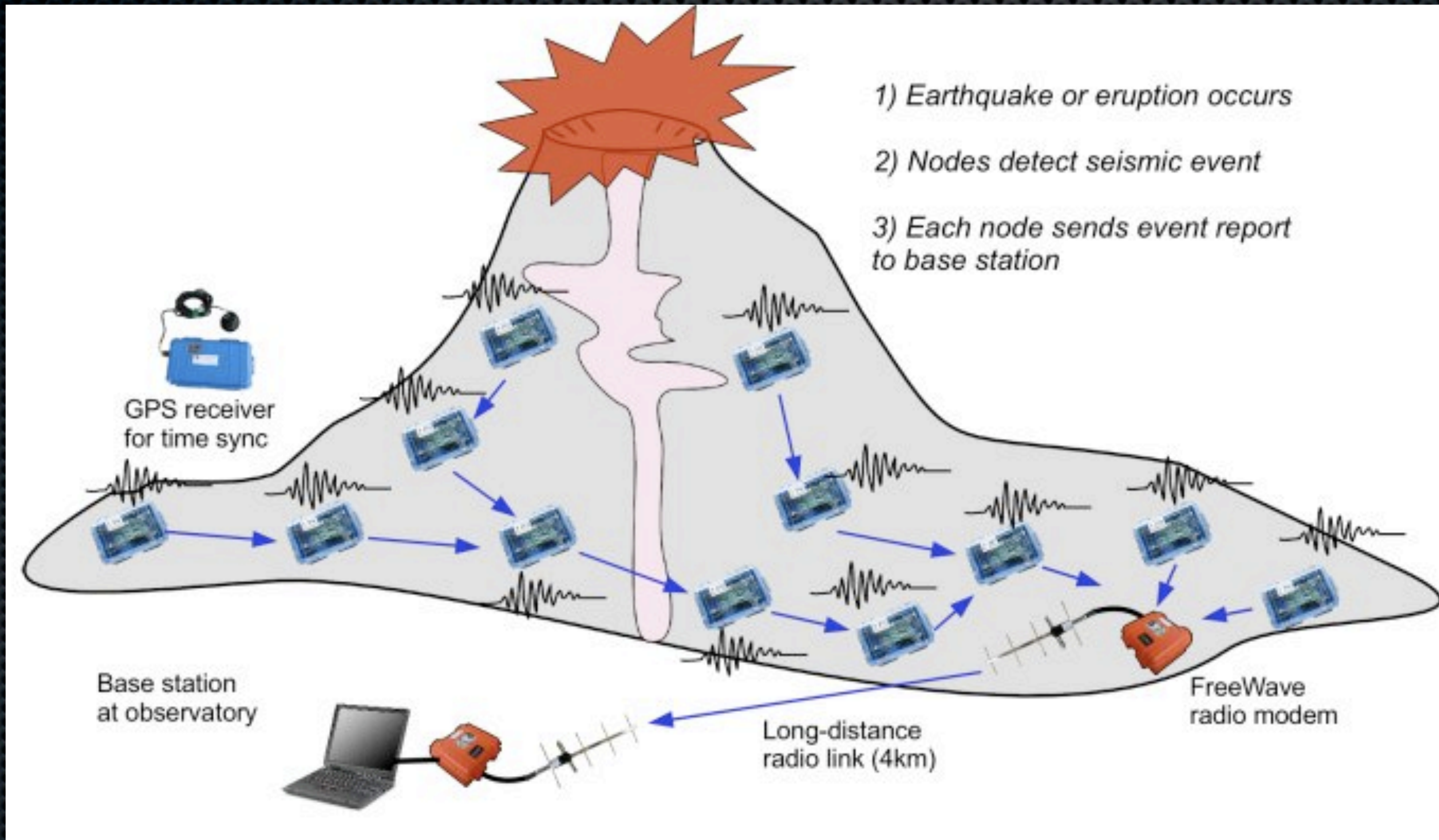
Sensor Network Applications

- Applications of WSN include:
  - Habitat and Ecosystem Monitoring
  - Seismic Monitoring
  - Civil Structural Health Monitoring
  - Monitoring Groundwater Contamination
  - Rapid Emergency Response
  - Industrial Process Monitoring
  - Perimeter Security and Surveillance
  - Automated Building Climate Control

ZebraNet

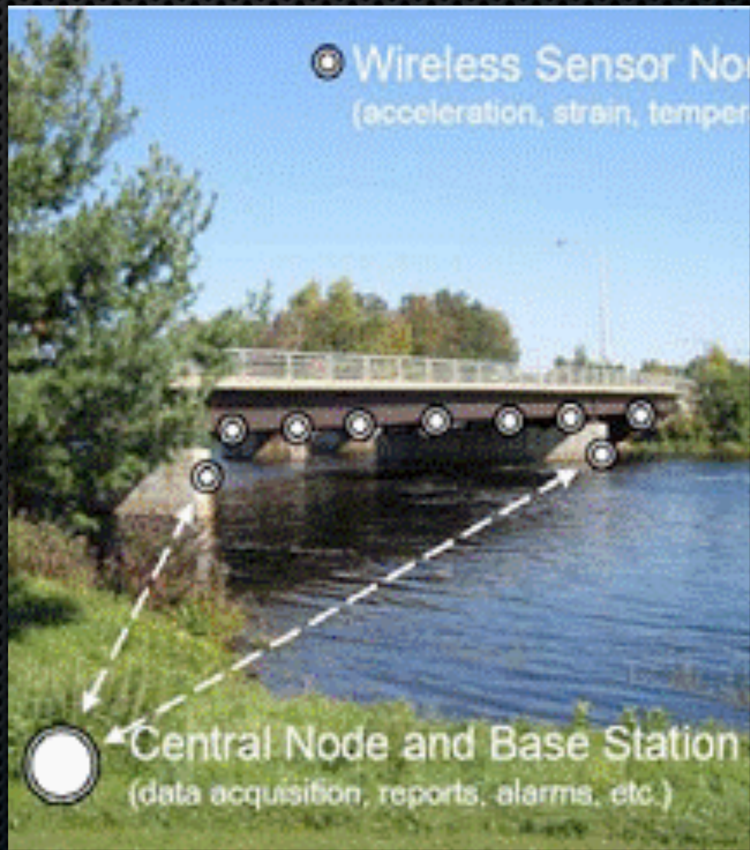
- ZebraNet: an application to track zebras on the field
- The objective of the application is to gather dynamic data about zebra positions in order to understand their mobility patterns.
- What are the motivations for the zebras to move? water? food? weather?
- How do they interact?
- The sensors are deployed in collars that are carried by the animals.
- The users are the biologists.

Vulcano Monitoring



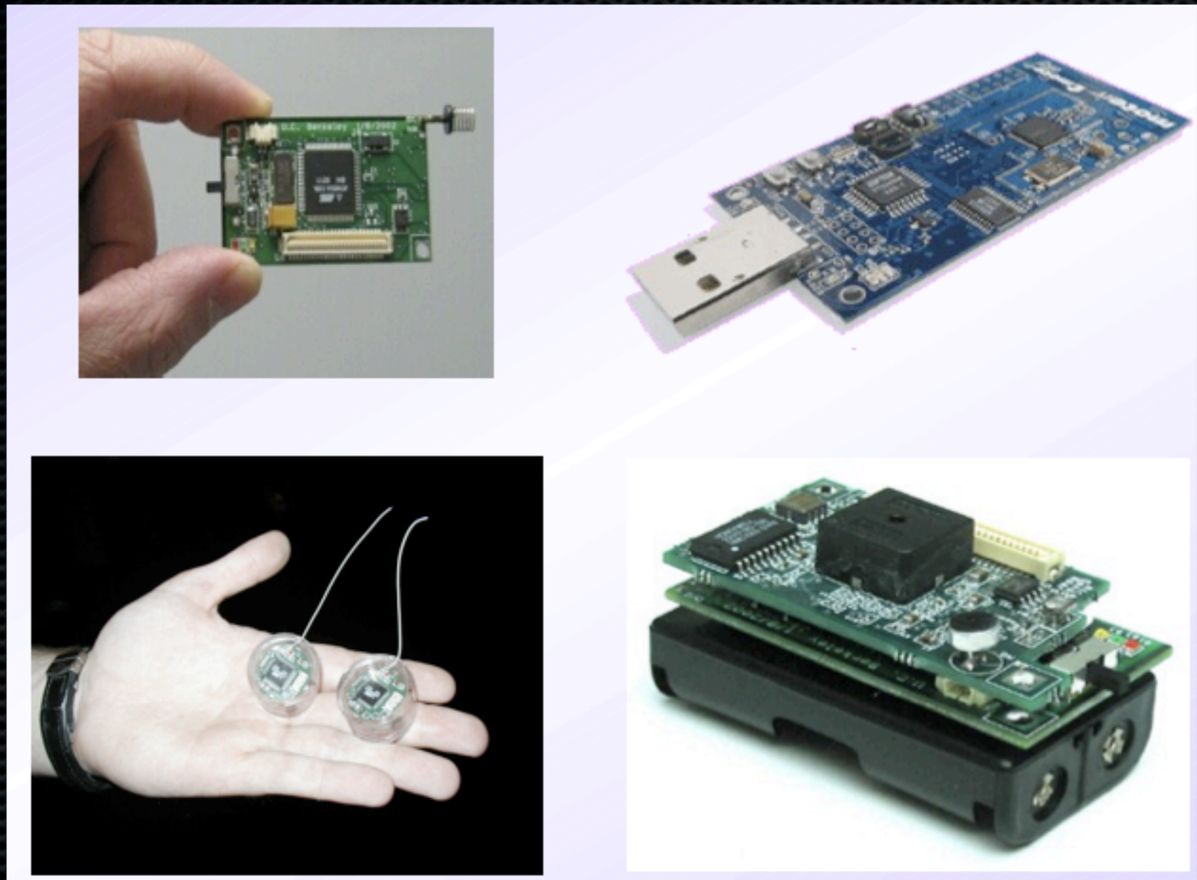
Sensor Network Applications

- **Bridge Monitoring**
- Structural health monitoring (SHM) is a sensor-based preemptive approach
- In California, 13% of the 23,000 bridges have been deemed structurally deficient, while 12% of the nation's 600,000 bridges share the same rating.
- New York may be the first state with a 24/7 wireless bridge monitoring system.



Mote anatomy

- **Processor** in various modes (sleep, idle, active)
- **Power source** (AA or Coin batteries, Solar Panels)
- **Memory** used for the program code and for in-memory buffering
- **Radio** used for transmitting the acquired data to some storage site
- **Sensors** for temperature, humidity, light, etc



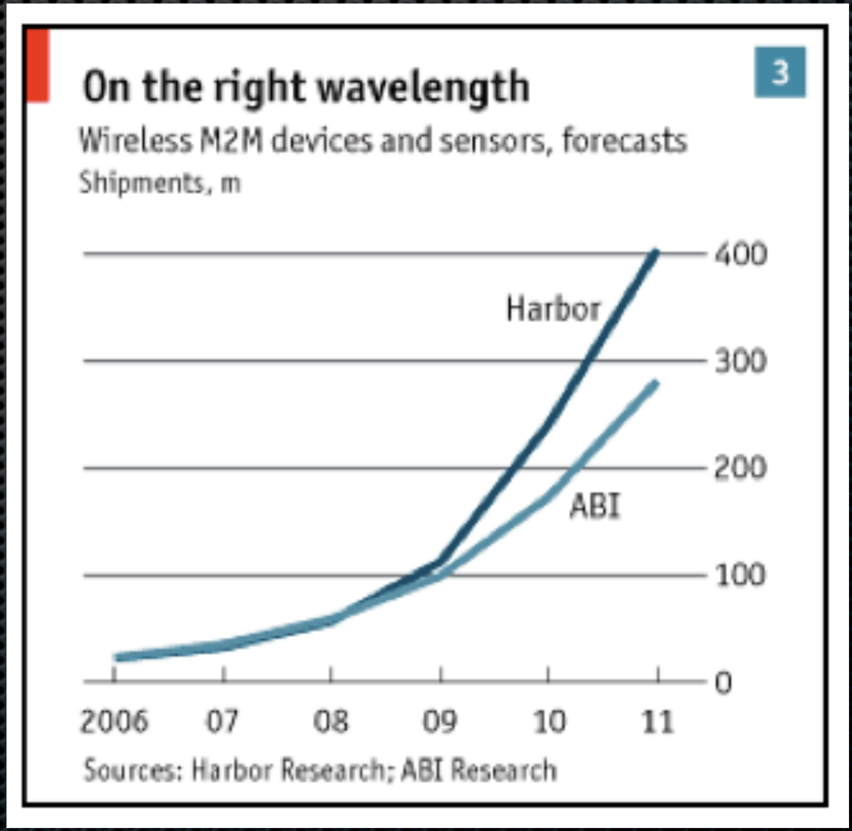
Potential of WSN

- US National Research Council report ("Embedded Everywhere"): **the use of wireless sensor networks (WSN) could well dwarf previous milestones in the information revolution.**
- MIT's Technology Review in February 2003 predicted: **WSN will be one of the most important technologies in the near future.**
- Nature, in the "2020 computing: Everything, everywhere" report, said that **WSN are going to be one of the most interesting technologies.**

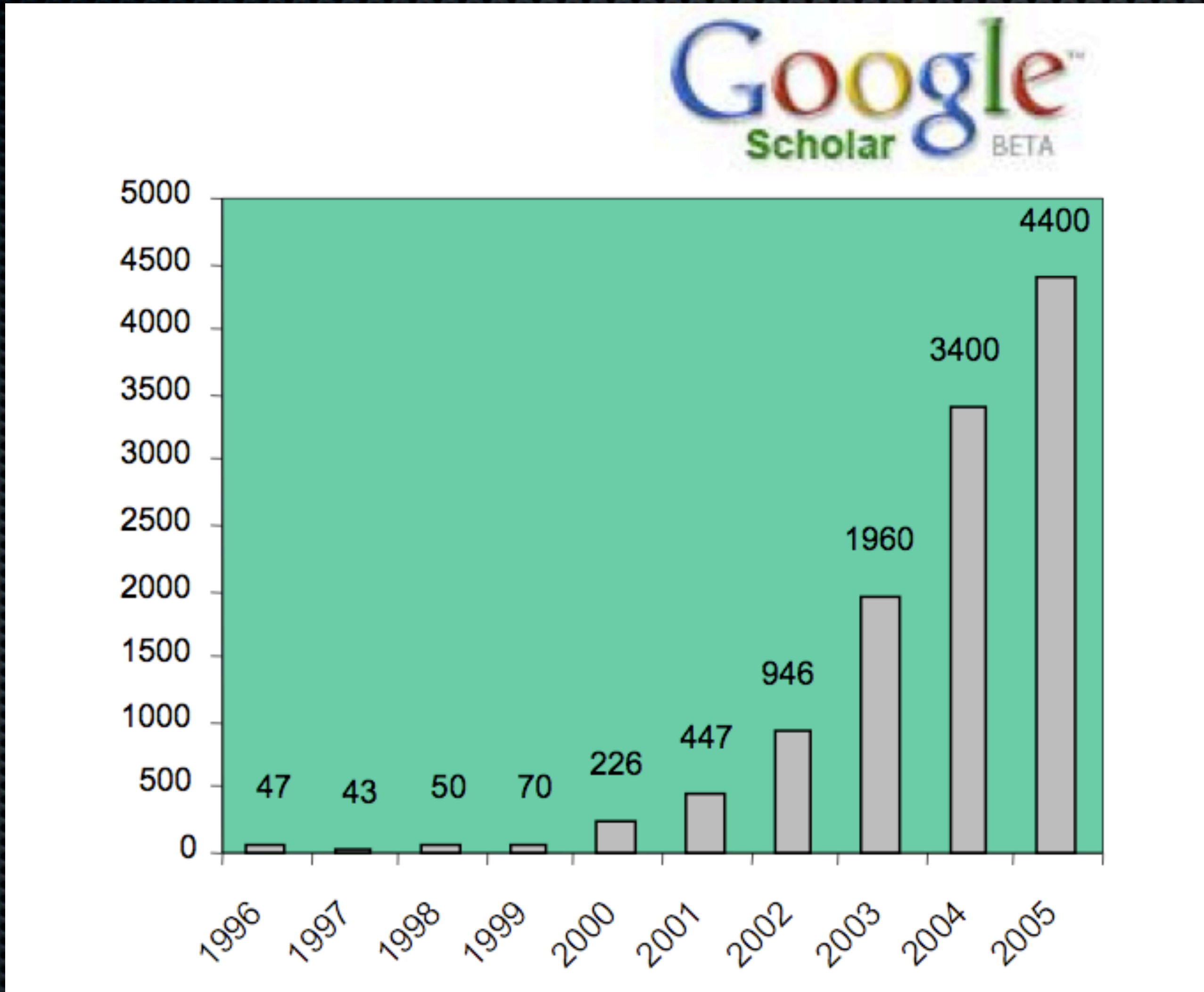
- There must be 100s of applications, I just need to adapt them to the Developing World!

Potential of WSN

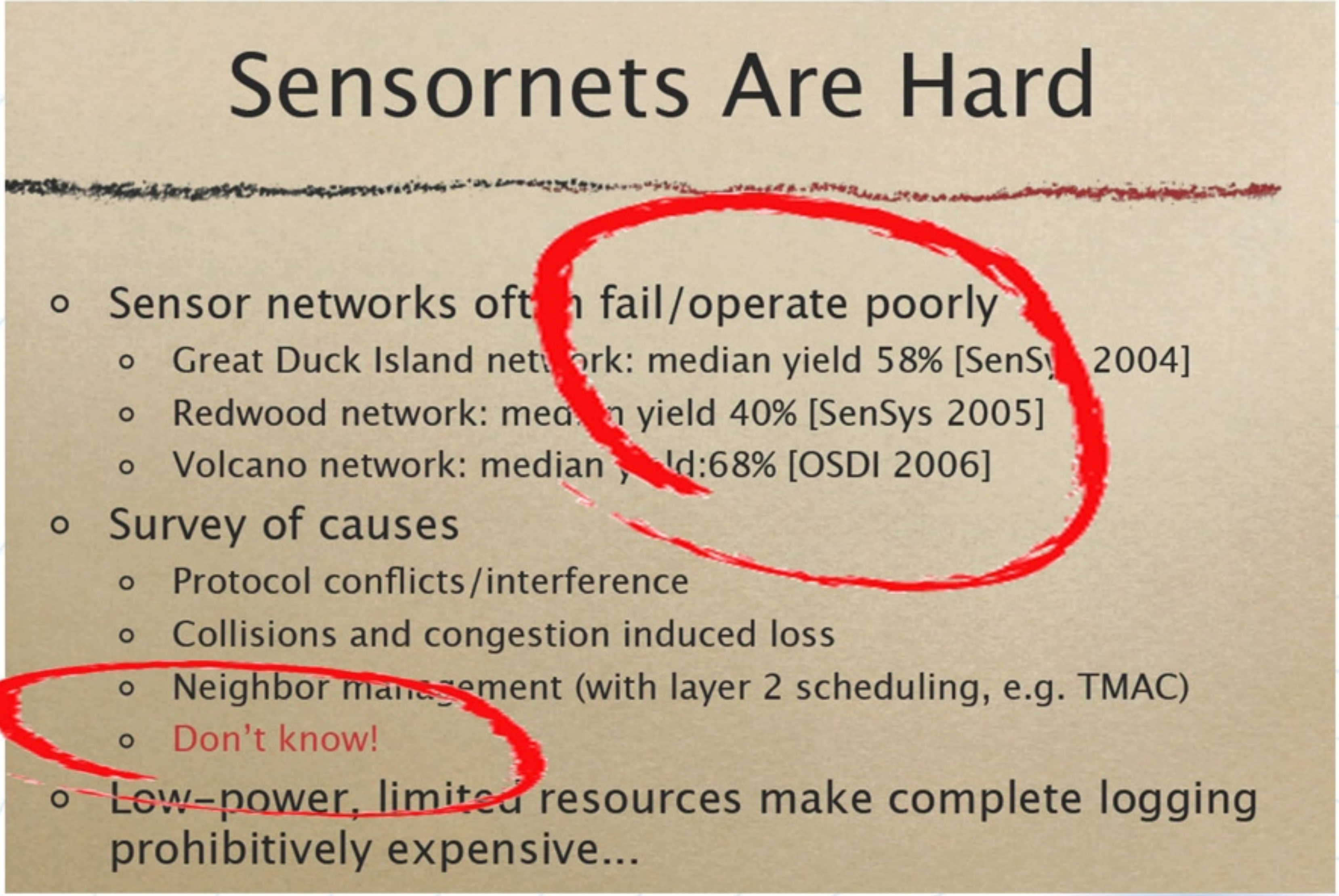
- The Economist, in April 2007, had an issue called "When everything connects".



Potential of WSN



Performance is Poor – Causes Are Not Understood



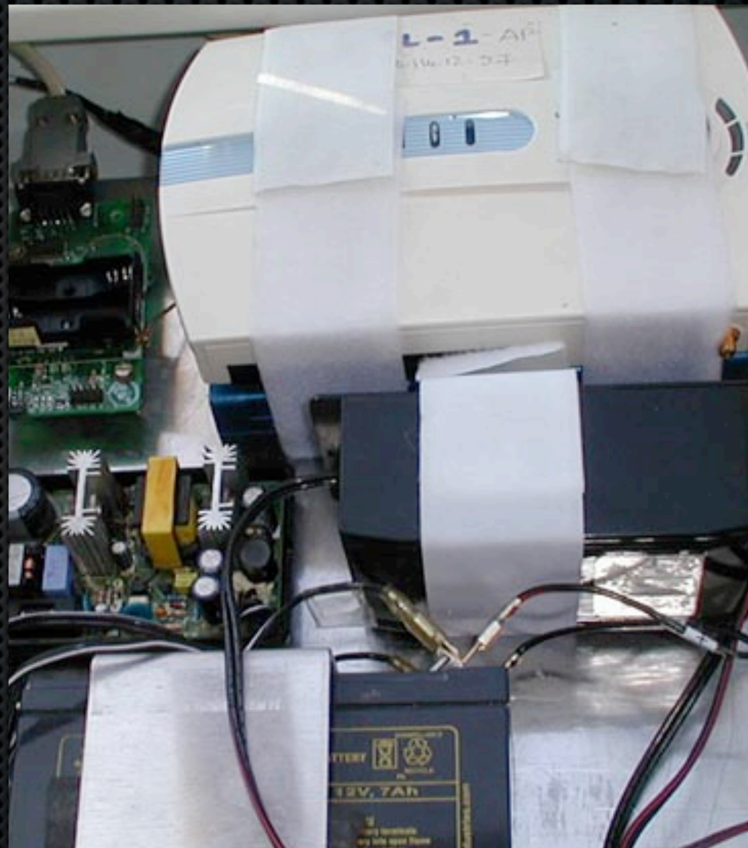
[Phil Levis, Stanford]

Market

- There are a couple of major companies producing WSN: Moteiv, Crossbow and Sun.
- The products they sell are quite different, but still require an expert to setup and use.
- A popular choice is **SunSPOT** by Sun. It is based on Java, so it is MUCH easier to program!
- Uses standard IDEs. e.g. NetBeans, to create Java code and integrates with J2SE applications.
- **Squidbee** is based on open source Arduino board and is very cheap.

WSN4D

- The four technological requirements that can make an ICT4D project successful [*]:
- 1) Autonomous Connectivity
- 2) Power resilience
- 3) Appropriate User Interface
- 4) Low-cost equipment
- * The case for Technology in developing regions, E.Brewer et al., IEEE Pervasive Computing



WSN4D

- **Environmental Monitoring**: landslides, flood detection
- **Agricultural**: assistance for irrigation
- **Water**: effective use of water resources, river level, pollution
- **Health**: HIV/AIDS (Intelesense Technologies in Ethiopia)
- **Scientific**: geophysical research, animal tracking

WSN4D

- Many challenges in deploying WSN in Developing Countries:
- - power consumption
- - cost of deployment
- - rugged and reliable
- - not many experiences

Water Quality

- UN Millennium Development Goal (2000): **'Reduce by half, by 2015, the proportion of people without sustainable access to safe drinking water.'**
- Every day, diarrhoeal diseases cause some 6,000 deaths, mostly among children under five.

Water Quality

- **1 billion people** lack access to improved water supply
- In sub-Saharan Africa, trends observed since 1990 indicate that neither the sanitation nor the drinking water target will be met by 2015.

Water Quality in Malawi

- Our plan is to use WSN to monitor water quality in Malawi, at the Blantyre Water Boards.
- Basic parameters to monitor includes **turbidity, pH and redox**.
- Other parameters will be considered pending the availability of low-power-consuming sensors.

Thank you for your attention!

I blog about WSN on www.wsnblog.com