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SCHOOL ON PHYSIC IN INDUSTRY

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PHYSICS IN INDUSTRIALIZED COUNTRIES

THE U.S. - A CASE STUDY

presented by

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These are preliminary lecture notes, intended for internal distribution to participants only.

PHYSICS IN INDUSTRIALIZED COUNTRIES

THE U.S. -- A CASE STUDY

I shall talk about physics in the U.S. since my knowledge covers that country, but I assume there are many truths that equally describe industrialized countries.

INTRODUCTION -- U.S. ENVIRONMENT

In the U.S., we graduate slightly in excess of 1000 Ph.D.'s in Physics per year. There are approximately 35,000 physicists in the APS. There are 60,000 represented by the AIP and its member institutes. In 1983-84 there were >1,067 Ph.D.'s granted and >5,045 granted for the five year period, as shown in Tables A (I) and A (II).

Table A(I)—Faculty, Enrollments, and Degrees Granted—Listed Departments with Ph.D.'s in Physics and/or Astronomy[1]

Research Specialty	1983-84 Faculty	Enrollment Fall 1983: Master's	Enrollment Fall 1983: Doctorate	No. of Degrees Granted 1983-84: Master's	No. of Degrees Granted 1983-84: Terminal Master's	No. of Degrees Granted 1983-84: Doctorate
Acoustics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Applied Physics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Astronomy	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Astrophysics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Atmos./Space Phys., Cosmic Rays	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Atomic & Molecular Phys.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Biophysics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Chemical Physics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Computer Science	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Electromagnetism	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Elem. Particles & Fields	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Energy Sources & Environ.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Engineering Physics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Fluids & Rheology	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Fusion & Plasmas	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Geophysics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
History & Philosophy	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Low Temperature Physics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Marine Sci./Oceanography	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Materials Sci./Metallurgy	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mechanics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Medical & Health Physics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Nuclear Physics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Nuclear Engineering	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Optics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Physics Education	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Polymer Physics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Relativity	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Solid State	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Systems Science	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Statistical & Thermal	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Other Experimental	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Other Theoretical/Math.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Other (specify)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Non-specialized	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Full-time Grad. Stud.	[illegible]	[illegible]				
Part-time Grad. Stud.	[illegible]	[illegible]				
First-year Grad. Stud.	[illegible]	[illegible]				
Median Years in Grad. Study (1983-84 Degrees)				*	*	**
Undergraduate Degrees, 1983-84 (1979-84): [illegible]						

[illegible]

Table A(II)—Faculty, Enrollments, and Degrees Granted—All Listed Departments[1]

Research Specialty	1983-84 Faculty	Enrollment Fall 1983: Master's	Enrollment Fall 1983: Doctorate	No. of Degrees Granted 1983-84: Master's	No. of Degrees Granted 1983-84: Terminal Master's	No. of Degrees Granted 1983-84: Doctorate
Acoustics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Applied Physics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Astronomy	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Astrophysics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Atmos./Space Phys., Cosmic Rays	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Atomic & Molecular Phys.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Biophysics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Chemical Physics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Computer Science	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Electromagnetism	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Elem. Particles & Fields	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Energy Sources & Environ.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Engineering Physics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Fluids & Rheology	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Fusion & Plasmas	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Geophysics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
History & Philosophy	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Low Temperature Physics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Marine Sci./Oceanography	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Materials Sci./Metallurgy	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mechanics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Medical & Health Physics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Nuclear Physics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Nuclear Engineering	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Optics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Physics Education	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Polymer Physics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Relativity	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Solid State	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Systems Science	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Statistical & Thermal	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Other Experimental	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Other Theoretical/Math.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Other (specify)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Non-specialized	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Full-time Grad. Stud.	[illegible]	[illegible]				
Part-time Grad. Stud.	[illegible]	[illegible]				
First-year Grad. Stud.	[illegible]	[illegible]				
Median Years in Grad. Study (1983-84 Degrees)				*	*	**
Undergraduate Degrees, 1983-84 (1979-84): [illegible]						

[illegible]

The Physics faculty members are close to 4,000, depending on degree granting status of the school, as seen in Table 5.

5. Personnel Engaged in Separately Budgeted Research[1]

	I	II
Professorial faculty	3,899	4,800
Other faculty	511	633
Postdoctoral appointments	1,581	1,744
Graduate students	5,579	7,127
Undergraduate students	1,608	2,047
Non-teaching research personnel	849	1,092
Total	14,027	17,473

[1]Column I represents totals for all departments which offer Ph.D.'s in Physics and/or Astronomy listed in the *1984–85 Graduate Programs in Physics, Astronomy and Related Fields.* Column II represents totals for all reporting departments in the *1984–85 Graduate Programs in Physics, Astronomy and Related Fields.*

There are shown in Table 6, the dollars spent on research in Physics Departments and on physics related research outside of Physics Departments.

6. Separately Budgeted Research Expenditures by Source of Support[1]

Department Research	I	II
Number of Departments Reporting	207[2]	298
% of Total Departments	69%	
Category		
Federal government	$365,041,708	$426,479,613
Canadian national government	10,298,099	10,374,749
State and local government	5,533,328	7,360,759
Canadian provincial government	1,032,595	1,932,599
Other government	1,202,874	1,427,318
Private, non-profit organizations	8,349,388	10,058,005
Business and industry	5,641,723	13,071,674
Other	11,452,997	12,816,187
Total[3]	$416,832,712	$492,120,900

Physics-Related Research Outside Department	I	II
Number of Departments Reporting	60	73
Category		
Federal government	$116,771,990	$121,336,990
Canadian national government	85,000	85,000
State and local government	698,000	862,000
Canadian provincial government	–	–
Other government	418,000	418,000
Private, non-profit organizations	797,700	801,700
Business and industry	4,448,500	4,545,500
Other	1,073,033	1,372,033
Total[3]	$124,292,223	$129,023,223

[1]Column I represents totals for all departments which offer Ph.D.'s in Physics and/or Astronomy listed in the *1984–85 Graduate Programs in Physics, Astronomy and Related Fields.* Column II represents totals for all reporting departments in the *1984–85 Graduate Programs in Physics, Astronomy and Related Fields.*

[2]Number of U.S. departments which offer Ph.D.'s in Physics and/or Astronomy was 191 which represented 97% of all such U.S. departments.

[3]The instruction to the departments for reporting information stated that the totals for Section 6 should equal those for Tables C and D. (See page x of the *1984–85 Graduate Programs in Physics, Astronomy and Related Fields.*) Due to some inconsistencies in reporting information, Section 6 totals are slightly different than those for Table C.

Table C–Separately Budgeted Research Expenditures

Research Specialty	Expenditures ($) I	No. of Grants[1] II
Acoustics	$ 1,413,739 (53)	$ 1,743,739 (59)
Applied Physics	2,828,908 (72)	15,566,952 (130)
Astronomy	35,770,798 (457)	38,700,487 (491)
Astrophysics	24,247,838 (278)	24,818,538 (288)
Atmospheric/Space Phys., Cosmic Rays	34,037,250 (427)	38,624,800 (489)
Atomic & Molecular Phys.	21,480,243 (394)	22,384,148 (413)
Biophysics	10,110,548 (185)	15,232,843 (283)
Chemical Physics	2,778,200 (41)	2,814,550 (49)
Computer Science	45,000 (1)	2,308,847 (28)
Electromagnetism	680,150 (12)	2,708,327 (48)
Elem. Particles & Fields	78,853,518 (418)	78,898,318 (434)
Energy Sources & Environ.	1,841,350 (62)	3,172,223 (83)
Engineering Physics	684,349 (8)	851,349 (13)
Fluids & Rheology	1,731,153 (27)	1,731,153 (87)
Fusion & Plasmas	20,804,348 (141)	25,100,481 (192)
Geophysics	2,401,178 (68)	3,463,978 (88)
History & Philosophy	101,000 (5)	189,000 (8)
Low Temperature Physics	10,820,171 (150)	11,038,404 (173)
Marine Sci./Oceanography	485,434 (12)	5,273,232 (105)
Materials Sci./Metallurgy	3,783,888 (45)	11,881,245 (147)
Mechanics	- (-)	(-)
Medical & Health Physics	1,900,787 (28)	2,108,852 (35)
Nuclear Physics	80,009,952 (382)	88,410,792 (389)
Nuclear Engineering	308,580 (10)	1,915,093 (32)
Optics	8,800,221 (178)	13,444,358 (191)
Physics Education	2,246,077 (95)	2,299,877 (95)
Polymer Physics	1,152,000 (24)	1,504,000 (34)
Relativity	3,540,820 (47)	3,560,777 (49)
Solid State	46,503,433 (988)	51,344,132 (1,088)
Systems Science	19,000 (1)	908,491 (24)
Statistical & Thermal	2,428,742 (58)	2,506,742 (58)
Other Experimental	21,441,000 (388)	23,000,464 (485)
Other Theoretical/Math.	3,550,501 (73)	3,700,501 (78)
Other (specify)	3,000,882 (28)	12,870,000 (118)
Total	$418,782,303 (5,858)	$484,880,521 (6,178)

[1]Column I represents totals for all departments which offer Ph.D.'s in physics and/or astronomy. Column II represents totals for all reporting departments in the *1984–85 Graduate Programs in Physics, Astronomy and Related Fields.*

Tables C and D show the breakdown of support according to subject matter.

Table D–Physics-Related Research Outside Department

Research Specialty	Expenditures ($) I	No. of Grants[1] II
Acoustics	$158,000 (5)	$158,000 (5)
Applied Physics	8,375,893 (61)	8,440,893 (63)
Astronomy	2,843,812 (55)	2,843,812 (55)
Astrophysics	2,142,000 (57)	2,142,000 (57)
Atmospheric/Space Phys., Cosmic Rays	10,358,129 (188)	21,728,129 (257)
Atomic & Molecular Phys.	1,844,000 (35)	1,844,000 (35)
Biophysics	1,783,000 (31)	1,803,000 (32)
Chemical Physics	10,945,520 (135)	10,945,520 (135)
Computer Science	1,298,763 (-)	1,298,763 (-)
Electromagnetism	592,000 (7)	592,000 (7)
Elem. Particles & Fields	197,000 (1)	197,000 (1)
Energy Sources & Environ.	2,817,845 (21)	2,817,845 (21)
Engineering Physics	8,678,000 (154)	8,678,000 (154)
Fluids & Rheology	- (-)	- (-)
Fusion & Plasmas	183,000 (5)	183,000 (5)
Geophysics	3,384,200 (88)	3,741,200 (119)
History & Philosophy	78,200 (2)	78,200 (2)
Low Temperature Physics	1,000 (1)	1,000 (1)
Marine Sci./Oceanography	1,325,000 (28)	1,325,000 (28)
Materials Sci./Metallurgy	8,910,000 (44)	8,918,000 (44)
Mechanics	639,000 (17)	639,000 (17)
Medical & Health Physics	550,000 (4)	550,000 (4)
Nuclear Physics	8,305,123 (11)	8,339,623 (12)
Nuclear Engineering	47,000 (1)	47,000 (1)
Optics	10,000 (1)	111,000 (6)
Physics Education	150,000 (1)	156,000 (2)
Polymer Physics	888,000 (13)	1,018,000 (17)
Relativity	- (-)	- (-)
Solid State	5,410,000 (19)	5,410,000 (19)
Systems Science	- (-)	- (-)
Statistical & Thermal	[illegible]	[illegible]
Other Experimental	18,800,438 (93)	18,870,439 (95)
Other Theoretical/Math.	1,400,000 (3)	1,400,000 (3)
Other (specify)	21,381,000 (188)	22,458,300 (188)
Total	$124,282,223 (1,183)	$129,623,223 (1,303)

[1]Column I represents totals for all departments which offer Ph.D.'s in physics and/or astronomy. Column II represents totals for all reporting departments in the *1984–85 Graduate Programs in Physics, Astronomy and Related Fields.*

All in all, you come to the conclusion that the pursuit of physics is a business of reasonable size.

WHERE DO PHYSICISTS GO?

This is difficult to quantify. Here is listed those sectors that do afford working careers for physicists.

1. UNIVERSITY COMMUNITY

A. Post Doctoral Appointments

We shall assume steady-state conditions. There were 1581-1744 positions filled in the 1984-85 time frame. This number fluctuates depending on the fluctuations in academic support programs, where dollars come from the government and the private sectors. The former had been decreasing, but there seems to have been a turn around over the past couple of years. The latter has shown only negligible increases and really contributes only a very small part of the total program. It should be noted that the number of post-docs exceeds the number of doctoral students produced, but as many people leave this sector as go into it, and so the total number of Ph.D. physicists looking for positions is approximately equal to the newly degreed candidates.

B. Faculty Appointments

There are between 3900 and 4800 faculty appointments. This number has extreme temporal fluctuations. As an example, it has been estimated that 90% of the physics faculty positions will have to be refilled in the 1990's. This temporal bunching will continue -- there is no mechanism to even out the fluctuation. When this demand occurs, the industrial pool will have to be utilized to fill the needs. There is also a demand by non-advanced degree granting schools. This would represent a small influence on the total demand.

2. GOVERNMENT LABORATORIES

Over the past several years there has been, if anything, a shrinkage of demand here. A guess would place the demand here at 10-20% of the supply. This category is divisible into subcategories.

A. Stand-alone Laboratories

These have been mission oriented and frequently the mission has changes. As an example, Oak Ridge National Lab used to be an atomic energy research lab. Other laboratories include:

The National Bureau of Standards, which was originally founded to worry about standards and metrology, but now does much more.

Los Alamos grew out of the Manhattan Project, and is now a general laboratory covering things in addition to weapons research.

Livermore is primarily a weapons lab, but it does many other things.

Brookhaven National Laboratory is a general laboratory engaged in academic types of research.

Argonne National Lab grew out of the Manhattan Project at the University of Chicago, and is new a broadly based science lab.

The Fermi Lab is the Country's leading high energy physics lab.

Sandia is a broadly based lab, also doing some weapons research.

B. University Associated Labs

A second category involves laboratories that are located at universities, but are government funded. Examples are:

at M.I.T.: the National Magnet Lab and Lincoln Labs. The former is known for its work in pushing the state-of-the-art in high magnetic fields, and the latter is a broadly based lab concentrating mostly in solid state.

at Cal Tech: The Jet Propulsion Lab, concerned with aerospace matters.

at Iowa State University: the Ames Lab, a broadly based lab originally centered on a neutron source.

at UC-Berkeley: the Lawrence Berkeley Laboratory, a very broadly based lab.

at Stanford University: the Stanford Linear Accelerator, engaged in high energy physics.

There are a number of laboratories being set up at universities with government and private funding, such as the Microwave Electronics Labs at North Carolina State University and one at the University of Texas in Austin, a Magnetics Research Institute at UC-San Diego, and the Center for Integrated Systems at Stanford.

There is still another class of lab falling outside of the above categories. These are privately run labs that exist entirely on contract support. Examples are SRI and Batelle. These are only few in number, and will get no further mention here.

3. INDUSTRY (Utilization of Physicists for Their Training)

I cannot quantify the number of physicists that go into industrial jobs that would utilize their talents and training. I would guess this would be somewhat n excess of 50% of the supply. These jobs can be further categorized as follows:

A. Industrial Research Labs

The nature of the work will vary with the place. Some labs (e.g., IBM, Bell Labs,) will do a broad spectrum of research from very fundamental to very applied. At the end of this paragraph I will give a brief description of the IBM Research Lab. I select this because of my familiarity. Other labs will have somewhat different mixes, and some will essentially do only applied research. Examples of the various types can be drawn from such labs as Boeing, Burroughs, DuPont, Exxon, Ford, General Atomics, General Electric, General Motors, Hewlett Packard, Hughes, Kodak, Polaroid, RCA, Shell, Texas Instruments, United Technologies, Westinghouse, and Xerox.

In any one of these labs there will be a broad spectrum of physics activities (broader in some than in others), spanning work from fundamental physics to very applied physics. In fact, some labs have gone through cycles. At one time Westinghouse was a very broadly based lab, today it is not so. General Electric used to have a wider scope of activities, but then it cut back. Today it may be widening its scope once more.

In order to give you examples of the various types of research being carried out in the various labs, I shall describe the work going on in the Research Division of IBM. It should be noted that certain labs do only very applied physics and some do both applied and fundamental. At IBM we do both, and it should be remembered that a subset of the work I describe may be exemplary of all of the work going on in a particular lab.

In the IBM Research Division there are a little over 3,000 people; 1012 of whom have Ph.D.'s, of which there are 266 Ph.D. physicists. Roughly 25% of our budget is in science and 75% is in applications. Physicists are hired in both categories, of course.

In science, most of the activities involve work in areas that are important to IBM and that serve as the underpinnings of IBM technologies. Examples are work in semiconductors, magnetics, superconductivity, surfaces, interfaces, polymers, ceramics, etc. The people in these activities strive to publish, give invited and contributed talks, go to meetings and in general, interact with the outside world. Hence, one of the prime consumers of their work is the outside community -- academia, government labs, and other industrial labs. IBM is also a prime consumer in that it is important for the Corporation to have a well founded base for their technological activities, to understand the limits

afforded by current phenomena and materials, to be able to evaluate new or alternate directions and technologies, and in general, to be able to predict and mold future developments.

There is a part of our science, about one quarter, that is somewhat different. This is science that is not so well related to IBM's needs, science that does not have a predictable or immediate payoff to the Corporation. Examples of this are: laser physics, astrophysics, biophysics, search for the magnetic monopole, measurement of the mass of the neutrino, neurological science, superfluid helium, etc. These activities do not have a direct impact on IBM, but we expect them to impact their fields. There is no point in our doing mediocre astrophysics, the work we do has to be significant and recognized as such in its field. So, it is true for all such "science for science sake" projects.

In the above, physicists are hired to work individually or in teams depending on the nature of the work. We might have an individual with a post-doc working in superfluid helium, or on the shapes of galaxies, or we might have a group of physicists working on 2-d electron conductivity in a Si or quantum hall effect in GaAlAs-GaAs layered materials. These physicists will generally belong to the American Physical Society and will attend physics meetings sponsored by the APS, the Materials Research Society, American Vacuum Society, Electrochemical Society, IEEE, etc. They interact with their peers in the outside world and with their peers within IBM. The pressure on them to publish is no less than it is in academia. The environment in which they function is very much similar to academia.

These science areas are not the only ones to hire physicists. The applications areas also afford a working environment for physicists. In this side, which comprises some 75% of the budget, we work on mainstream and on alternative technologies. As examples:

> In logic and memories, the mainstream technology is silicon, and we have extensive programs investigating processing, devices, circuits, packaging, design automation and layout, testing, lithography, etc. As for alternatives, we used to think that Josephson Junction Technology

afforded an alternative to silicon, but after many years of pursuing this we concluded that there was not technical viability and we dropped the program. Today we pursue GaAs Technology in a depth comparable to silicon. Whether GaAs will be an alternative or a complement to silicon remains to be seen.

In storage the mainstream technology remains that of magnetic coatings on media -- rigid discs, floppy discs or tapes. Here we try to understand new magnetic materials, new ways of preparing surfaces, greater planarity, new methods of storage and encoding, etc. We previously thought that magnetic bubbles could be an alternate to this magnetic storage technology, but we concluded that it did not have the necessary economic viability. Today we are pursuing various schemes in optical storage and whether any one will turn out to be a successful alternate or complement remains to be seen. Similarly, in other areas we pursue alternatives. In displays we look at the CRT and liquid crystal displays. In printers we investigate impact and non-impact printers. Similarly for the rest of the IBM product line.

In all of the above we utilize physicists, engineers, ceramists, chemists, metallurgists, computer scientists, psychologists, linguists, etc. The physicists have their training in diverse areas; solid state, quantum optics, particle physics, low temperatures, plasmas, gaseous or electron physics and even astrophysics. The brightness, the talents, the drive, and the disposition of the physicists are of greater importance than the training.

B. Development Labs

In American industry there is more than just the research lab. There are product development areas and manufacturing areas. Again, I will call upon my familiarity with IBM to describe the involvement of physicists here.

The Research and Development budget of IBM is somewhere between 2 and 3 billion dollars. To cover the Development part of the R&D we have laboratories all over the world -- U.S., Germany, France, England, Japan. In these locations they pursue advanced technology and development of advances to the product line. Different locations have different missions determined by that product for which a lab has responsibility. Some labs will be largely hardware oriented (E. Fishkill, Burlington, San Jose); some will be systems oriented (Boca Raton, Austin, Rochester); and some will be software oriented (Santa Theresa). Hence, some labs will hire more physicists than others. The activities that will be pursued there will be similar in nature to the activities in the applications area of Research, except the emphasis will be on the near term and on product cycle timing. Again, different disciplines will be utilized and the physics work going on will be practiced by Ph.D.'s with diverse backgrounds.

C. Manufacturing Facilities

If we proceed to the Manufacturing areas, we will probably find far fewer Ph.D. physicists utilized here than in the development areas, but there will be some. And, there probably should be more. It is interesting to note the reversal of hierarchy in Japan compared to America. In the U.S. the research lab is perceived to be the most prestigious and the development lab less, with the manufacturing activities the least. In Japan, it is exactly the reverse with the manufacturing function being deemed the most important. In fact, with the exceptions of a few countries and labs (Philips in Eindhoven and some Japanese facilities) it is mainly in the U.S. that one can find large research activities supported by a private company.

At IBM we have started an operation called the Manufacturing Research Laboratory. This started out in our main Research lab and its intent was to be aware of the latest activities and advances in Research, and to try to apply them to manufacturing problems, present and future. This activity has recently been scaled up to close to 200 people and consists of such activities as robotics, nondestructive testing, packaging and processing. It has hired quite a few physicists, especially in the last two areas. But, what is more important, a number of physicists have transferred into it from other research activities which brings us to the important subject -- career paths and changes -- but, before that, we should discuss another role of physicists.

4. PHYSICISTS NOT ENGAGED IN PHYSICS

Many physicists have gone from practicing physics into non-physics related activities. As examples, we at IBM have physicists in charge of a communications functions, in charge of general administrative function, in charge of recruiting, etc. We have found that scientifically trained people bring to bear in problems analytical ability and a facility for sorting through facts and reducing problems to the essential ingredients. As a result, they frequently can handle non-technical issues with greater facility, incisiveness and speed than non-technically trained people. We have many examples of successful conversions of acting physicists to managers of administrative functions.

There are cases where physicists have gone into market analysis, investment analysis, and in sales. These numbers aren't great, but they aren't zero.

The physicists that have gone into these fields have generally come from areas in which they utilized their training and, hence, once again the question of changing career paths comes up.

5. CAREER PATHS

There are many transitions physicists make: industry to university, university to industry, university to university and industry to industry. In addition, and probably the most common one is where there is a shift from fundamental to applied research. There are also field changes such as physics to biophysics, high energy to solid state, etc.

These shifts will occur for a myriad of reasons. I believe the most common one is what I call intellectual menopause. When a scientist gets his Ph.D. he'll get a job doing research. Frequently the challenge disappears from his environment and this causes an ennui. It occurs most generally 10 to 15 years from his degree grant. He takes stock of his technical life. Without new challenge, he sees himself doing the same thing for the next 15 years and becomes depressed by the prospect. He tries to create his own challenges and he'll make one of the transitions alluded to earlier -- he'll change jobs, fields, or even wives. (Note that in an industrial environment it is up to his management to assure that his job environment maintains its challenge).

A very common trend in industry is for the physicist to want to switch from basic to applied work. It doesn't happen to everyone, but it does happen to a sufficiently large number that special mention must be made of it. After a period of doing fundamental science, the physicist will frequently want to work in areas where he can see readily the utilization of his work. As a result, he will switch from the basic science area to the applications area described above. This switch will mostly be within Research, but not entirely so. Frequently physicists in applied programs want to get involved with product development and transfers from Research to various Product Development labs will ensue. Sometimes there will be transfers into manufacturing facilities, although that is much more rare. However, transfers from basic sciences to the Manufacturing Research Lab described above are common.

Special mention should be made about the transition of physicists from industry to universities. This goes on all the time. There is a snobbism on the part of many in academia in rating university careers over industrial careers. You will hear more of this on February 12 when Choyke and others will talk about the Training of Physicists. However, this snobbism is decreasing in time, in my perception. There have been waves of such transfers between industry and universities. In the early 60's we saw many physicists go from Bell to various universities. In the 90's we will see another exodus when universities will have to replace 90% of their staffs and there will be a limited supply from newly trained Ph.D.'s. It has reached such a practice today that many fresh Ph.D.'s have plans to work industry for a 5 year period or so, and then using that experience, to parlay it into an academic position. Some carry through their intentions, but most find it too rewarding, financially and intellectually, to leave industry.

There is even a small migration from Universities to Industry. We find that happening more and more as the difficulty at obtaining government funding increases.

CONCLUSION

I have tried to give you a flavor of Physics in an Industrialized country. In particular, it is Physics in the U.S. and it emphasizes physics in the industrial community. It attempts to portray the activities and the career paths open to graduating Ph.D. Physicists.

During the remainder of the course we have selected examples of specific industries with tutorial lectures demonstrating the types of problems that physicists work on in that particular industry.

We will then discuss the training of physicists for industry, from the U.S. viewpoint and the viewpoints of other industrialized countries.

Lastly, we hope to give you some impressions of the industrial and academic physicists, their attitudes and beliefs or misbeliefs.