The Abdus Salam
International Centre
for Theoretical Physics

HADRON BUILDERS:
A TACTILE BOARD GAME FOR THE STANDARD MODEL

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Conference on Non-Digital Game-Based Learning in Physics and STEM Disciplines

WHY HADRON BUILDERS?

THE NEED FOR TANGIBILITY

Particle physics is a difficult and abstract subject for high school students because they cannot see or touch the subatomic world. "Hadron Builders" is a non-digital tabletop game designed to solve this problem. It makes the Standard Model of Particle Physics concrete, visible, and interactive.

GAME FUNDAMENTALS & OBJECTIVES

Target Audience: High School Students (Grades 9-12)

Duration: 40-50 Minutes (12 Rounds / Cosmic Calendar)

Number of Players: 2-4 Players

Objective of the Game:

- The goal is to collect fundamental particles (Quarks, Leptons) from a chaotic environment.
- Players use fundamental forces to combine them.
- They create the most stable matter forms to complete their particle laboratories.
- At the end of twelve rounds, the player with the highest stability score wins.

GAME COMPONENTS (BOX CONTENTS)

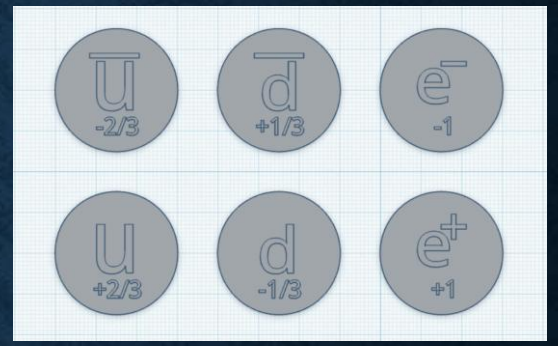
4-Player Box Contents	Quantity	Description
Game Board	1	Includes 4 Laboratory Panels, 1 Collider Pool, and a Cosmic Calendar
Matter Tokens	60	24 Up Quarks (u): 8 red, 8 blue, 8 green. Back side is anti-u. 24 Down Quarks (d): 8 red, 8 blue, 8 green. Back side is anti-d. 12 Electrons (e-): Colorless. Back side is positron (e+).
Gluon Springs (Clips)	40	Copper wire springs with 3D printed "C" clips on both ends. Used to physically connect quark tokens.
Force Cards	35	15 Gluon, 10 Photon, and 10 W Boson cards. Represent the fundamental forces of nature.
Event Cards	10	Introduce chaotic space events.
Quantum Die	1	Used for survival rolls.

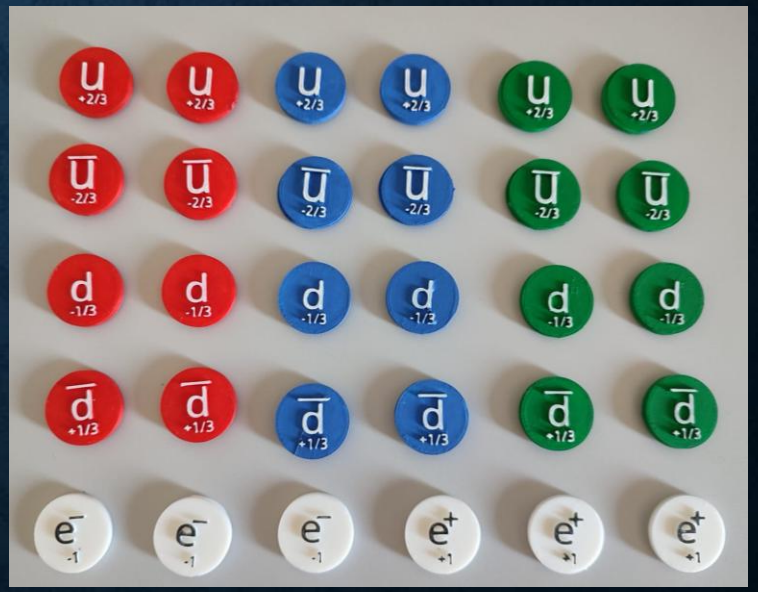
GAME BOARD

- A "Laboratory Panel" (Personal Area) for each player and a "Collider Pool" in the middle.
- There is a Cosmic Calendar (Round Tracker) counting from 1 to 12 on the edge of the board. At the beginning of each round, the first player moves the round stone one step forward. This helps students track the current round on the table because they can easily forget which round they are in during the game.
- Force Cards and Event Cards are randomly mixed in the deck, and players draw a card when it is their turn.

DOUBLE-SIDED MATTER TOKENS

- All matter tokens are double-sided.
- Every particle has an antiparticle. Double-sided tokens save game material and teach the symmetry principle at the same time. Flipping the token turns matter into antimatter.
- The tokens are designed in CAD programs and 3D printed. The symbols and charge values on them are raised. This design allows visually impaired students to feel the pieces and join the particle building process. It also makes local production easier with low cost materials.
- The red, blue, and green colors on the tokens represent the 'Color Charge' of quarks. They are distributed equally so the color confinement rule works easily during the game.





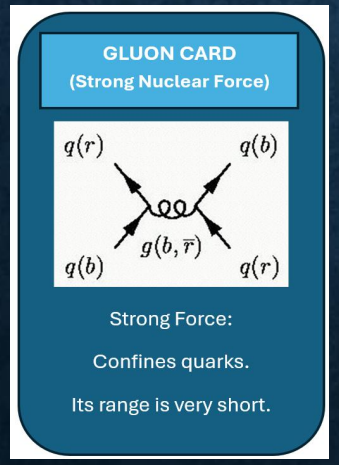
GLUON QUANTUM SPRINGS (3D CLIPS)

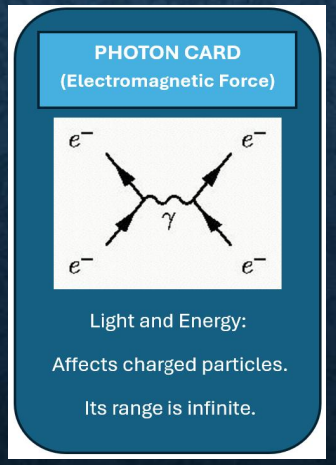
- Gluons act like a spring in physics. As you try to separate quarks, this spring stretches and the force increases. Its design is a wavy spring in the middle. It has "C" shaped clips on both ends that perfectly fit the token edges. To keep the production low-cost, the springs are made of hand-coiled copper wire, and only the clips are 3D printed.
- Students attach 1 piece between two tokens to make a Meson. To make a Baryon (Proton/Neutron), they arrange the tokens in a triangle and attach 3 pieces between them.
- In the Hadron Builders game, students use 3D printed tokens and "Gluon Clips". They physically build particle structures. Students do not just read the color confinement rule from a paper. They learn it with their muscle memory while physically locking different colored tokens.

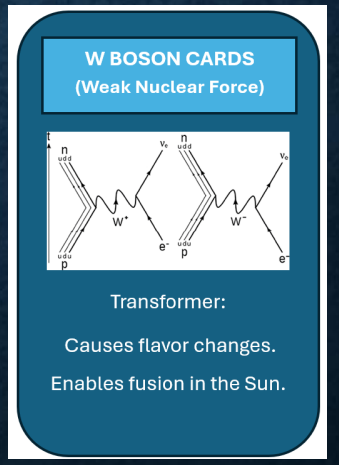
FORCE CARDS

The Role of Force Cards

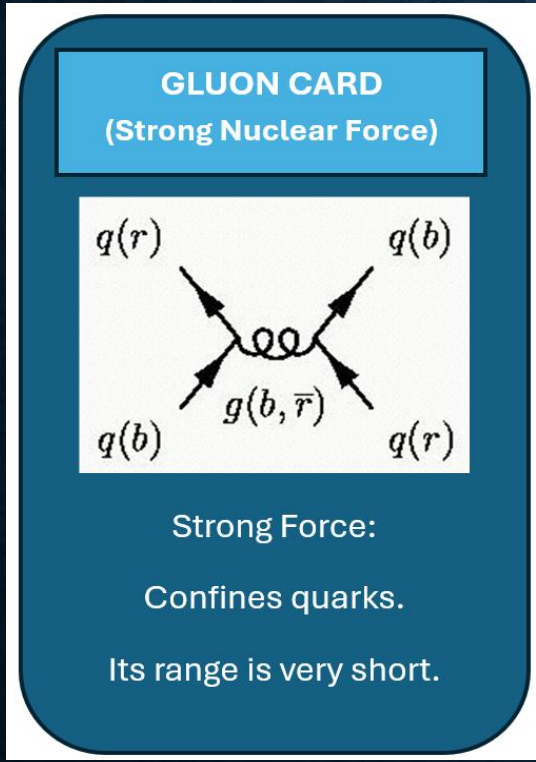
- Force cards are designed to represent the fundamental forces of nature.
- They give players the power to interact with particles and build matter.
- These cards turn abstract physics concepts into simple, physical actions.
- Students learn how the universe works naturally, without memorizing complex rules.





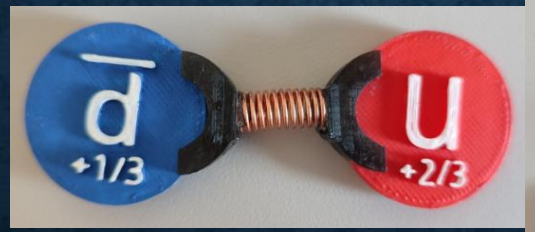


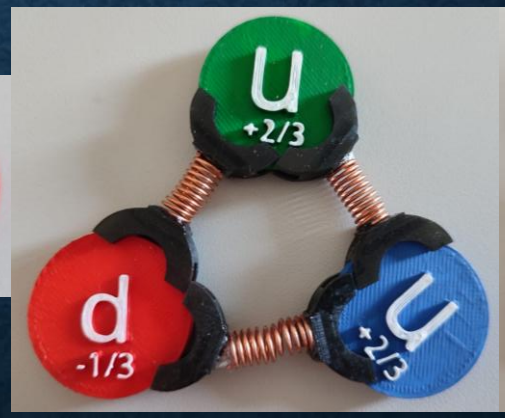
FORCE CARDS
1.GLUON CARD (STRONG NUCLEAR FORCE)

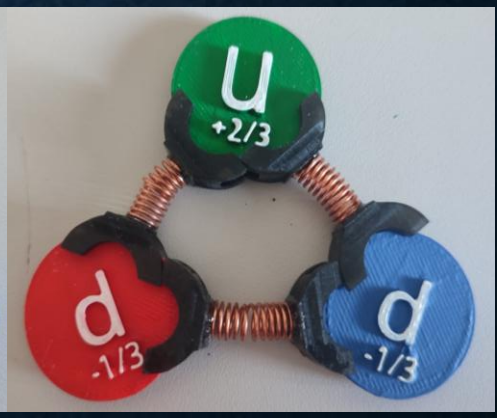


This card is used to combine two or three quarks to make Meson, Proton or Neutron.

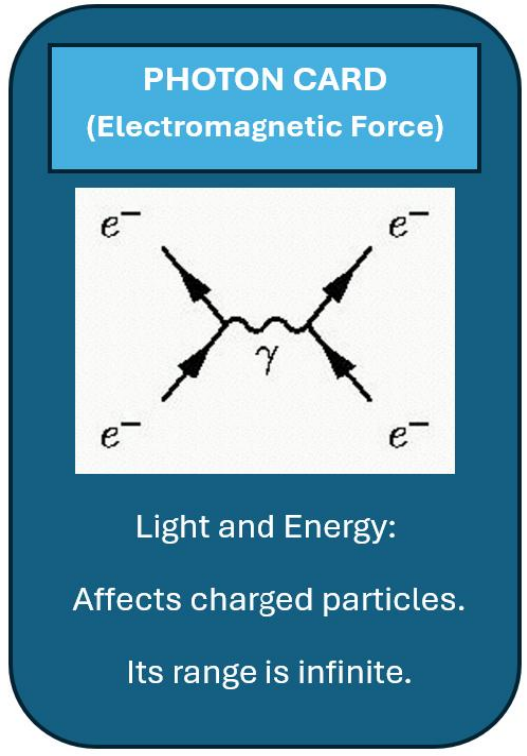
- Quarks cannot stay together without Gluons (Color Confinement). When students spend 1 Gluon Card, they take the required number of 3D Gluon Clips from the pool (1 for Meson, 3 for Baryon) to build those particles.







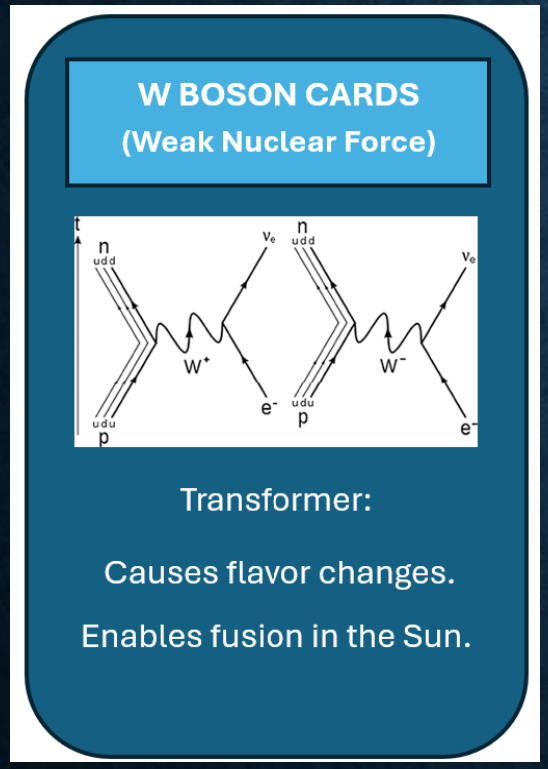
FORCE CARDS
2. PHOTON CARD (ELECTROMAGNETIC FORCE)



The card is used to bind a nucleus (Proton) and an electron to make an atom (Hydrogen), or to spend as in-game energy.

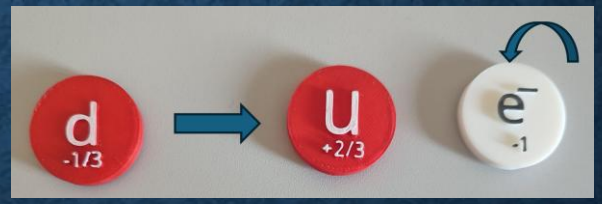
- When students use a Photon card to create a Hydrogen Atom, they do not connect the electron token to the proton with any 3D tool.
- Gluons physically confine quarks (Color Confinement) but electrons exist in a Quantum Cloud (Probability Distribution). Their exact locations cannot be known. So, electrons are not rigidly attached to the nucleus on the table. They are just placed side by side.

FORCE CARDS
3. W BOSON CARDS (WEAK NUCLEAR FORCE)

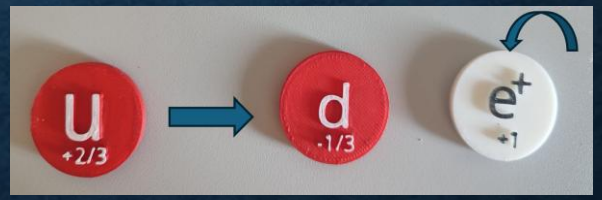


This card is used to make a Flavor Change.

- **Beta-Minus Decay:** A player who changes their Down Quark (d) into an Up Quark (u) gets 1 free Electron (e-) token from the pool.



- **Beta-Plus Decay:** A player who changes their Up Quark (u) into a Down Quark (d) gets 1 free Positron (e+) token from the pool.



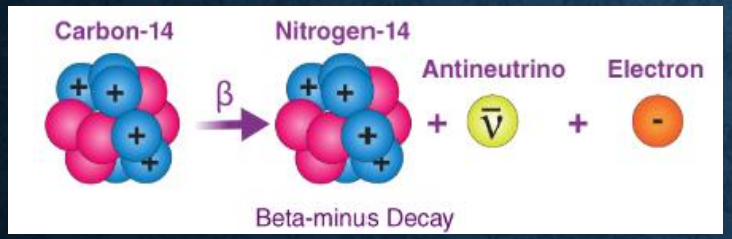
Pedagogical Simplification: A neutrino is also released in real beta decay (antineutrino in beta-minus, neutrino in beta-plus). Neutrinos do not carry a charge and are almost massless. So, they are not included in the game components for simplification at the high school level. Full decay equations can be given during classroom discussions.

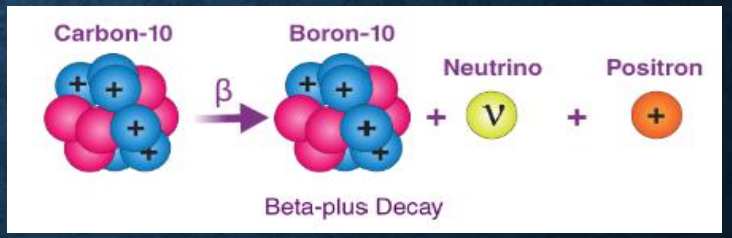
EDUCATIONAL PURPOSE

- The symmetry between matter and antimatter is more than just a rule. It becomes a hands-on experience with physical materials.
- Students do not memorize complex decay rules. They discover them naturally to get a free token in the game.
- Students learn that the W Boson is a real source of free electrons in nature.
- The W Boson is very valuable in the game. Students can freely swap a quark and get a free electron to build hydrogen.

EDUCATIONAL PURPOSE

- The positron (e+) is not used in making baryons or atoms. It is a natural product of Beta-Plus decay. Its function in the game is to make the matter-antimatter balance visible. For this reason, Beta-Plus decay does not bring a direct gain like Beta-Minus. This is an intentional design choice. It makes the player choose Beta-Plus mostly to adjust their quark flavor strategically.



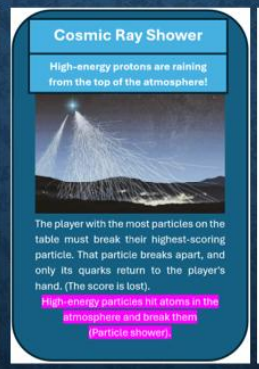


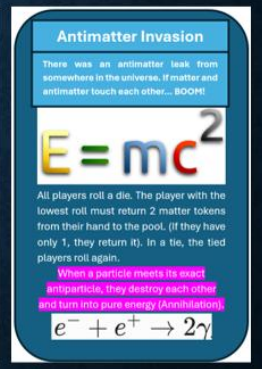
- The increase of positrons on the table prepares the ground for the "Antimatter Invasion" or "Pauli Exclusion Principle" cards. When those cards are drawn, players with too many matter tokens are at a disadvantage. Therefore, while using the W Boson provides the necessary electron for a hydrogen atom, it also creates a strategic risk.

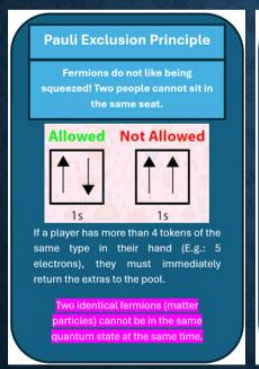
EVENT CARDS

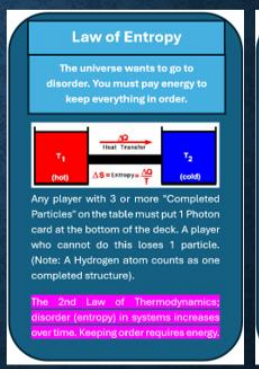
The Role of Event Cards

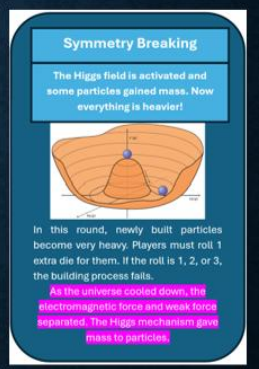
- Event cards are designed to make the game more enjoyable.
- They show that the game is much more than a simple particle puzzle.
- The cards help students understand physics visually through clear images.
- Students get hands-on practice and learn the rules naturally by playing.







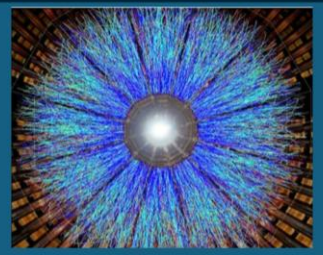




EVENT CARDS

Quark-Gluon Plasma

The universe got very hot! We are back to that hot soup right after the Big Bang. Everything is free!

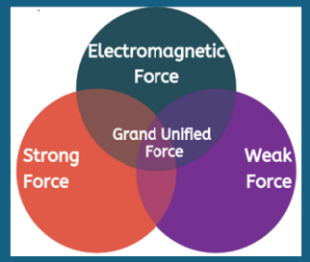


In this round, players do not need a "Gluon Card" to combine quarks. Gluons are free!

In the first moments of the universe, the temperature was so high that quarks moved freely.

Grand Unification

At very high energies, all forces act like a single "Super Force".



In this round, all "Force Cards" become JOKERS. Players can use any force card instead of another.

The dream of physicists; the unification of electromagnetic, weak, and strong nuclear forces under a single mathematical roof.

Cosmic Ray Shower

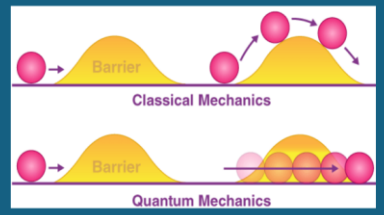
High-energy protons are raining from the top of the atmosphere!

The player with the most particles on the table must break their highest-scoring particle. That particle breaks apart, and only its quarks return to the player's hand. (The score is lost).

High-energy particles hit atoms in the atmosphere and break them (Particle shower).

Quantum Tunneling

Even if you don't have enough energy, you can pass through the wall. Like a ghost!



The player with the lowest score blindly takes 1 random token from any opponent's hand.

The probability of a particle passing through an energy barrier that it cannot overcome according to classical physics.

Antimatter Invasion

There was an antimatter leak from somewhere in the universe. If matter and antimatter touch each other... BOOM!

$$E = mc^2$$

All players roll a die. The player with the lowest roll must return 2 matter tokens from their hand to the pool. (If they have only 1, they return it). In a tie, the tied players roll again.

When a particle meets its exact antiparticle, they destroy each other and turn into pure energy (Annihilation).

$$e^- + e^+ \rightarrow 2\gamma$$

EVENT CARDS

Heisenberg's Uncertainty

If you know the position, you cannot know the speed! The location of the tokens in your hand got a bit mixed up.

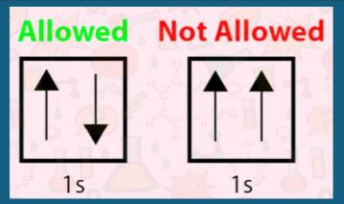
$$\Delta x \, \Delta p \geq \frac{\hbar}{2}$$

All players give all the matter tokens in their hand to the player on their left. (Tokens on the table stay safe).

In quantum mechanics, we cannot know all properties of a particle exactly at the same time.

Pauli Exclusion Principle

Fermions do not like being squeezed! Two people cannot sit in the same seat.

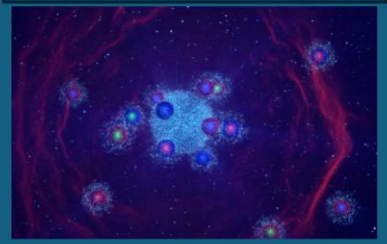


If a player has more than 4 tokens of the same type in their hand (E.g.: 5 electrons), they must immediately return the extras to the pool.

Two identical fermions (matter particles) cannot be in the same quantum state at the same time.

Dark Matter Web

An invisible mass holds the universe together. Your galaxy is safe.

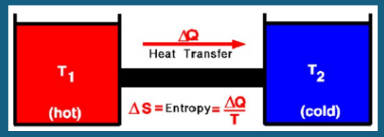


In this round, players cannot attack other particles or roll a decay die. All particles have a full protection shield!

Dark matter provides the extra gravity that prevents galaxies from falling apart.

Law of Entropy

The universe wants to go to disorder. You must pay energy to keep everything in order.

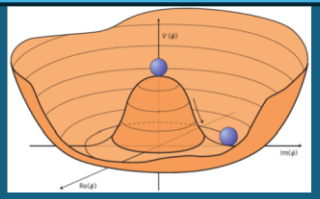


Any player with 3 or more "Completed Particles" on the table must put 1 Photon card at the bottom of the deck. A player who cannot do this loses 1 particle. (Note: A Hydrogen atom counts as one completed structure).

The 2nd Law of Thermodynamics; disorder (entropy) in systems increases over time. Keeping order requires energy.

Symmetry Breaking

The Higgs field is activated and some particles gained mass. Now everything is heavier!



In this round, newly built particles become very heavy. Players must roll 1 extra die for them. If the roll is 1, 2, or 3, the building process fails.

As the universe cooled down, the electromagnetic force and weak force separated. The Higgs mechanism gave mass to particles.

EVENT CARDS CATEGORIES

1. Accelerator (Game Saver) Cards: They unlock the game when students are stuck and cannot produce anything.

Quark-Gluon Plasma

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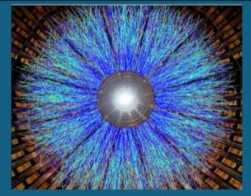

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Grand Unification

At very high energies, all forces act like a single "Super Force".

In this round, all "Force Cards" become JOKERS. Players can use any force card instead of another.

The dream of physicists; the unification of electromagnetic, weak, and strong nuclear forces under a single mathematical roof.

2. Balancer (Leader Slowing) Cards: They equalize the competition on the table again when one player collects too many points.

Cosmic Ray Shower

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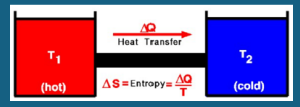

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The 2nd Law of Thermodynamics; disorder (entropy) in systems increases over time. Keeping order requires energy.

3. Interaction (Competition) Cards: They prevent players from only looking at the tokens in front of them. They connect everyone at the table. They keep the class awake.

Heisenberg's Uncertainty

If you know the position, you cannot know the speed! The location of the tokens in your hand got a bit mixed up.

$$\Delta x \, \Delta p \geq \frac{\hbar}{2}$$

All players give all the matter tokens in their hand to the player on their left. (Tokens on the table stay safe).

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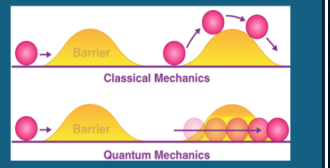

The player with the lowest score blindly takes 1 random token from any opponent's hand.

The probability of a particle passing through an energy barrier that it cannot overcome according to classical physics.

GAME FLOW (HOW TO PLAY?)

STEP 1: STARTING THE GAME

•Every player gets a Starter Set.

Starter Set	**2 Up Quarks** **2 Down Quarks** **1 Electron** **1 Gluon Card**

•The particle types are fixed for everyone, but the colors are distributed randomly.

Educational Purpose:

- This makes the player face the color confinement problem directly. If players drew completely randomly, a student might get 5 identical tokens and wait for 3 rounds.
- Giving everyone an equal starting point makes the game about strategy, not luck. It also makes the game flow fast in a 40-minute class.
- Random colors preserve the quantum randomness of the universe while providing a pedagogically fair balance.

STEP 2: MAKING PARTICLES

Particle	Required Resources	How to Build & Rules
Meson	1 Quark + 1 Antiquark (u-anti u, u-anti d, d-anti u, d-anti d) 1 Gluon Card	To make a Meson, students flip a quark token to make an antiquark. They combine them and attach 1 Gluon clip between them. The colors of the tokens do not matter in meson synthesis. **Pedagogical Simplification:** Printing "anticolor" on tokens would make things very complicated, so colors do not matter for mesons.
Proton	2 u + 1 d (uud) 1 Gluon Card	To make a Proton, students need 2 Up Quarks and 1 Down Quark. They arrange the tokens in a triangle. They use 1 Gluon Card to get 3 Gluon clips from the pool to connect them.
Neutron	1 u + 2 d (udd) 1 Gluon Card	To make a Neutron, students need 1 Up Quark and 2 Down Quarks. They arrange the tokens in a triangle. They use 1 Gluon Card to get 3 Gluon clips from the pool to connect them.
Hydrogen Atom	1 Proton + 1 e- 1 Photon Card	To make a Hydrogen atom, students combine 1 Proton and 1 free Electron by using a Photon Card. Students place the electron freely next to the proton on their panel. They do not use a mechanical clip.
Beta Minus Decay	1 Down Quark (d) 1 W Boson Card	To perform Beta Minus Decay, students change a Down Quark (d) into an Up Quark (u) and get 1 free Electron (e-) from the pool.
Beta Plus Decay	1 Up Quark (u) 1 W Boson Card	To perform Beta Plus Decay, students change an Up Quark (u) into a Down Quark (d) and get 1 free Positron (e+) from the pool. **Rule:** Students CANNOT flip the positron to use it as an electron.

STEP 2: MAKING PARTICLES

Educational Purpose:

- Flipping the token lets students physically feel the symmetry between matter and antimatter. The idea that every particle has an antiparticle becomes concrete.
- For Protons and Neutrons, students physically lock three different colored tokens using Gluon clips. They learn the color confinement rule with their muscle memory, rather than just reading it from a paper.
- Finally, by building an atom, students see the big picture: they learn that while quarks build protons and neutrons, these particles and electrons build atoms.

STEP 3: THE QUANTUM DIE (SURVIVAL ROLL)

•Whenever students build a new Neutron or Meson, they must roll the Quantum Die.

Structure	When to Roll	Survival Condition
Meson	Immediately after building	Extremely unstable. Survives only if you roll a 6. Disappears on 1, 2, 3, 4, or 5.
Neutron	Immediately after building	Fairly stable. Decays only if you roll a 1. Survives on 2, 3,4, 5, or 6
Protons & Hydrogen	Do NOT roll	Completely stable.

Educational Purpose:

- Protons are effectively stable.
- The neutron rule gives an 83% chance of living. This simulates the free neutron life very well.
- The meson rule gives a 17% chance of living, making it a quantum miracle.
- Students can easily learn the real rules of the universe: Protons are extremely stable, neutrons mostly survive, and mesons mostly disappear.

STEP 4: DRAWING CARDS

•At the start of every turn, students draw 1 Matter Token and 1 card from the deck.

•Students can use as many Force Cards as they want to build particles. They keep drawn Force Cards in their hands to plan their moves. After using a Force Card, students put it at the bottom of the deck.

•If students draw an Event Card by chance, they must open it immediately and read it aloud. The effect happens instantly. After that, they draw one more card from the deck. They put the used Event Card face down at the bottom of the deck.

Educational Purpose:

- Allowing multiple Force Cards in one turn speeds up the gameplay and lets students create exciting particle combos.
- Students draw an extra card because they should not lose their normal move. Otherwise, the Event Card becomes a punishment.
- Putting cards at the bottom allows events to happen again to simulate a cyclic universe model. In the quantum universe, nothing is certain. It is a way to make students feel the chaotic nature of the universe.

STEP 5: END OF THE GAME AND SCORING

•The game lasts for 12 rounds on the Cosmic Calendar.

•Players count their Stability Score. The player with the highest score wins.
•Students get 10 points for a Hydrogen Atom, 5 points for a Proton, 3 points for a Neutron, and 1 point for a Meson.
•Only the score of the top structure is taken.
•Free quarks left in their area give a -1 point.

Educational Purpose:

- Reaching round 12 represents the cooling of the universe.
- The Hydrogen Atom gives the highest score because it is the most stable structure in the universe.
- A meson is highly unstable and disappears in a very small fraction of a second. The game is designed to show this instability. Building a meson is easy, but it only gives 1 point and quickly disappears.
- Free quarks left in their area cost 1 point because they cannot be found alone in nature. This enforces the Color Confinement rule.

END GAME SCORING TABLE (STABILITY SCORE)

Synthesized Structure	Content	Stability Score	Scientific Explanation
Hydrogen Atom	Proton + Electron	10 Points	The most common and stable structure in the universe.
Proton	u + u + d + (3 Gluons)	5 Points	It is the most stable baryon in the universe.
Neutron	u + d + d + (3 Gluons)	3 Points	Unstable when free outside the nucleus.
Meson	Quark + Antiquark + (1 Gluon)	1 Point	Extremely unstable, doomed to disappear instantly.
Free Quarks	Single tokens left in the laboratory	-1 Point	They cannot be found alone in nature due to the Color Confinement rule.

Only the score of the top structure is taken. There is no nested scoring.

MODULAR USE ACCORDING TO CLASS LEVEL

- Event cards can be used step-by-step. This way, 9th and 10th-grade students do not feel overloaded with too many rules at the same time.
- The core game (collecting tokens, force cards, stability die) can be played on its own.
- Event cards are an optional expansion added to this core.
- The first 5-card Basic Set is a subset of the 10-card Full Set.
- This modular approach allows the game to scale to different groups with the same box.
- The levels are just a suggestion. The teacher can choose the set based on the class level.

MODULAR USE ACCORDING TO CLASS LEVEL

Level	Number of Cards	Event Cards Used
Grade 9 (Core Game)	0 Event Cards	No event cards are used. The core game only uses matter tokens, Force Cards, and the stability die. Students first learn the basic building process and the color confinement rule.
Grade 10 (Basic Set)	5 Event Cards	In this balanced set, Quark-Gluon Plasma and Grand Unification speed up the game, Cosmic Ray Shower slows the leader, Quantum Tunneling connects players, and Antimatter Invasion completes the theme.
Grades 11-12 (Full Set)	10 Event Cards	This level adds five new cards to the Basic Set: Heisenberg's Uncertainty, Pauli Exclusion Principle, Dark Matter Web, Law of Entropy, and Symmetry Breaking. Students do not learn the old cards again. They just learn new topics like the Higgs Boson.

REAL CLASSROOM EXPERIENCE

- I played this game with my 9th and 10th-grade students.
- It helped them a lot to learn basic particle physics.
- I gave them a pre-test and a post-test on basic concepts. Their test scores increased clearly.
- However, they did not fully understand some hard concepts in the Event Cards.
- So, I decided to use the Event Cards step-by-step for different grades.

CONCLUSION

- Hadron Builders is not only a physics game, but also an inclusive and hands-on STEM learning tool. Students learn abstract physics concepts by touching, building, and playing. The game supports active learning, tactile learning, and teamwork in the classroom.
- The game is made from low-cost materials. It can be easily used in remote areas with limited resources. The raised symbols on the 3D pieces allow visually impaired students to join the particle building process. With its modular structure, the game can be adapted for different grade levels and learning needs.
- In this project, I worked hard to keep the game fun while preserving real physics. I believe Hadron Builders can make modern particle physics more understandable, accessible, and enjoyable for high school students.

FUTURE WORK

- My main focus today is to introduce the game mechanics.
- Next year, I will play this game with many more students and collect detailed data.
- But most importantly, I am here today to get your valuable feedback.
- I want to create the best version of this game with your ideas and suggestions.

THANK YOU VERY MUCH

FOR YOUR ATTENTION

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