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PIEAS Society for Physics
Unravelling Beyond Horizons

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Unravelling Beyond Horizon

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Adivsor's Message

It gives me immense pleasure to congratulate the PIEAS Society for Physics on the publication of this edition of the Physics Magazine. The Society continues to play a vital role in cultivating a culture of scientific curiosity, academic excellence, and intellectual engagement among students of PIEAS.

Through its diverse and well-organized initiatives such as the "Let's Talk Physics" seminar series, mathematics competitions, and the quarterly newsletter "Zenith", the Society has provided students with multiple platforms to express their ideas, enhance their understanding of physical sciences, and develop critical and analytical thinking skills. These activities not only strengthen classroom learning but also inspire teamwork, confidence, and innovation.

The publication of this magazine is another remarkable effort in that direction. It reflects the dedication, creativity, and enthusiasm of both students and faculty members who share a passion for exploring the frontiers of physics.

I extend my appreciation to the editorial team and Society members for their continued efforts in promoting scientific awareness and excellence at PIEAS. I am confident that this magazine and the Society's ongoing activities will continue to inspire our young physicists to pursue inquiry, innovation, and discovery with greater zeal.

Dr. Shakeel Ur Rehman,
Faculty Advisor,
PIEAS Society for Physics.

Director's Message

It was around two years ago, in the same month of October, when I was entrusted with leading the Publications domain of PSP. From the very first day, I had one goal in mind — to launch a magazine during my tenure, alongside our quarterly newsletter.

To be honest, the idea of an annual magazine wasn't entirely new. My predecessor and his team had envisioned it and even laid some groundwork, but for various reasons, it could not be materialized at that time. Now, by the grace of Almighty Allah, that long-standing dream has finally been realized, and I have come to understand why it took time — such efforts require patience, teamwork, and persistence.

I am deeply thankful to my amazing team for standing by me throughout this journey. They are a hardworking and creative group of individuals, and the pages that follow are living proof of their dedication. Each of them contributed something unique — from planning to design, writing, and editing — and made this magazine possible.

Special thanks to our advisory board members, especially Dr. Tariq Siddique and Dr. Muhammad Irfan, for their continuous guidance and encouragement. I am also grateful to all the writers who contributed their articles, and to our fellow students from other universities who joined in and shared their work with us.

This magazine represents not just the efforts of a team but the spirit of collaboration, curiosity, and creativity that defines PSP. I hope you enjoy reading it as much as we enjoyed bringing it to life.

Zahid Islam,
Director Publication,
PIEAS Society for Physics.

How did the Path to Physics Appear?

Dr. Nasir M. Mirza

Chief Scientist (R), PIEAS

A student once asked me how I came to like physics, and what led me to adopt it as my field. Later, many members of my family also gradually turned to physics. So I began to reflect: how did this actually happen? Slowly but surely, we all found ourselves heading toward physics. Then it occurred to me that perhaps the environment in our home played a major role, where many influences came together to shape my inclination.

In particular, our mother had a deep interest not only in Arabic and Persian but also in mathematics and science. She read and taught with genuine passion. Our father, on the other hand, had a love for Urdu and English literature. He had collected hundreds of books at home. But I can say with certainty that what inspired us the most was the overall atmosphere of Government College. The environment there, the people, and the revered teachers were a great source of inspiration, encouraging us to read with genuine interest.

Getting admission to Government College Rawalpindi was a new and unique experience for me. There, I encountered individuals of exceptional character and habits. For four years, I had the privilege of learning from exemplary teachers. Each had a distinct style, personality, and way of teaching; their attire and manner of speaking were all different. But one common trait they all shared was their extraordinary knowledge and deep humanity. They were all masters of their respective subjects. I had never before seen so many renowned individuals gathered in one place.

In my first year, I studied pre-engineering subjects. The teachers I had for chemistry, physics, and mathematics were all remarkable. Mr. Dost Muhammad, Mr. Hanif Malik, and Mr. Riaz Ahmed Bhatti taught us physics and also supervised our lab work. The college laboratories were spacious rooms filled with large tables. Sometimes the equipment was placed on the tables, sometimes stored in cabinets underneath. The chemistry and biology labs resembled grand museums. Large charts were displayed on the walls. Many preserved specimens of insects and animals were kept in large glass showcases. On the tables were various bottles, test tubes, and beakers.

Teachers were always seen working inside the labs. On the other hand, most of the math teachers who came in turns had left for foreign scholarships, which caused us some difficulties. But then we met Mr. Qayyum Abid, Mr. Sarwar Kamran, and Mr. Abu Ubaid Faiz.

Among them, I found Mr. Faiz to be the most multi-dimensional personality. When he taught me mathematics, it felt as though I was also simultaneously studying physics and English literature. His personality was deeply immersed not only in mathematics but also in English and Urdu literature. He was a highly learned man, having read thousands of books.

He was never seen without a book. Whether traveling, walking, or conversing, he always had a book in hand. He used to tell us, “If you love knowledge, always keep a book with you.” Among students, he was extremely popular and respected. Always dressed elegantly, he would stroll through the college corridors in his unique style. From afar, he appeared to be a most impressive personality. He would always emphasize neat and clean dressing. From him, I learned logic, various branches of mathematics including difficult subjects like group theory, number theory, and topology. He instilled in us a love for books, art, and the connection between English literature and the mathematics necessary for physics.

Among the shining stars of the college's physics department, Mr. Riaz Ahmed Bhatti stood out prominently. He was an outstanding physics teacher. He had received a gold medal from Punjab University and authored three books. Once, I sat in one of his classes. After the class, he asked me what I liked. I replied that I was enjoying mathematics. He said, “To understand the wonders of nature, it is essential to enter physics — and its language is mathematics.” I asked, “Isn’t physics a difficult subject?” He replied, “To uncover the secrets of the universe, whether in the tiniest or the largest phenomena, understanding physics is essential.”

When I got to know him better, he included me in the review process of a book he was writing on electricity and magnetism. I often had long conversations with him after class. He would listen patiently, answer every question, and never stopped me from asking more. I learned many life lessons from him. Whenever I visited him, I usually found him working in the lab. Smiling, he would invite me to join his experiments — sometimes showing Newton’s rings, sometimes hydrogen spectral lines, or doing electricity and magnetism experiments. He would demonstrate phenomena like resonance with great clarity. At the same time, he would explain the entire process methodically. Two lab technicians worked closely with him and learned from him. Physics was his life. He, along with other teachers, had set up the F.Sc. and B.Sc. laboratories. He would test the equipment himself by doing the experiments. Both he and Mr. Dost Muhammad related many life matters to various concepts in physics, often referencing books. Around that time, I was also introduced to the four volumes of the Berkeley Physics Course. Mr. Bhatti said, “These books are great for understanding physics,” so we studied them during our B.Sc.

One admirable trait in our teachers was that they never discouraged questioning. They always provided thoughtful answers and highlighted the beauty and significance of the subject.

The atmosphere at college had other wonderful aspects too. For example, many renowned Urdu poets and writers were part of our college, including the famous Qayyum Nazar, Niaz Fatehpuri, Majid Siddiqui, Jameel Azar, and Mr. Zaidi. I had the opportunity to Majid Siddiqui’s class for two years.

I had the opportunity to attend He always came to class wearing a three-piece suit and large glasses, carrying books toward the library. His ghazals and poems were often published in newspapers. Everyone knew that he was the author of several books. He blended humor and satire into his teaching, often introducing both classical and modern poets and prose writers. His lectures were full of insightful comparisons and deep thoughts. Even though his classes started late, the room would be full, eagerly waiting for him to arrive with something new.

The English faculty was equally impressive, especially Principal Mr. Jelani Kamran. When I met him, I was amazed. He had a profound command of criticism and English literature. Every lesson with him was a journey into wonder. After one or two meetings, he told me to visit him for English writing corrections. So I would regularly go to his office, and he would correct many pages with his red pen, explaining a lot along the way. I continued taking new essays to him for several months. The affection shown by a college principal was a wonderful memory that remains etched in my mind.

Most of our mathematics, chemistry, and physics teachers also gave time outside regular classes. That was the first time I heard of the “zero period” — from 7:30 to 8:30 a.m., before official college hours. Mr. Qayyum Abid taught first- and second-year mathematics during this period for many months, openly inviting students to attend. It was famously said that if you brought any unusually hard problem to him, he'd solve it on the spot. We'd rush out of the house at 6:30 a.m. to attend, because if we were late, we'd have to stand. It was all free — no one ever charged a penny. It was more like an open challenge: "Whoever wakes up early can attend." Later, I also encountered zero semesters at the Center for Nuclear Studies, which reminded me fondly of college. My brothers, who studied at the same college one by one, were also fortunate to learn from the same teachers, and we all studied eagerly and with great joy.

Our love for physics began at Government College. The teachers there instilled a passion that made me think, "If these teachers, who are authors of books and conduct brilliant experiments, can learn physics so wonderfully, why can't I? I will try to do even better." The college labs were where I saw accurate experiments in action. Whatever I read in books, the teachers demonstrated clearly and allowed us to repeat and teach others. The teachers were a unique breed, constantly pushing us forward and insisting, "You are better than us; you can go further and do great work."

Most of them had calm temperaments, no arrogance, immense humility, and high moral standards. They embodied freedom of thought and intellectual openness, with deep individuality. It was there that I first heard about Russian, American, British, and European scientists, writers, and philosophers. I learned about great musicians from Germany and Austria, and painters from Britain, Russia, and Europe who worked on landscapes, blending colors like blue and red to create images close to reality and nature. I also met people in Pakistan working in similar fields. There, I got the chance to think about physics in a creative way.

In the electronics lab, I saw large systems in operation. I witnessed many things we had only heard of before. It was at Government College that I developed a broader perspective, learned logic and reasoning, and discovered how to learn new ideas from physics experiments. Later, I met many professors at Quaid-i-Azam University, the Center for Nuclear Studies, and abroad in several universities. I worked with many teachers, but the real wonder of physics first opened up to me at Government College — and it left a lasting impression.

On the other hand, our mother always advised us to observe great teachers closely: "See what quality makes them exceptional." What I found common in all was a sincere simplicity, a remarkable ability to understand nature, and the same sense of wonder found in children. I saw this same trait in great researchers. When I visited Landau, Germany, and met Nobel Laureates — around 50 of them — I saw that they too had a childlike awe. The most prominent quality in all of them was their amazement in observing nature. They channeled this wonder into creativity and applied their knowledge accordingly.

This innocent wonder and effort to blend tradition with knowledge was so powerful that it drew us toward physics and science. Certainly, the hallmark of a great teacher is their capability, but their character, ethics, and everyday conduct leave a lasting impression on students — and it is this impression that inspires one to choose the path of knowledge.

My International Internship (Journey and Achievements)

Muhammad Abu Bakar
MS Medical Physics, PIEAS

I am Muhammad Abu Bakar, a researcher with a background in mathematics, medical physics. After completing my BS in Mathematics from the University of the Punjab in 2023, I joined the MS in Medical Physics program at PIEAS.

In 2024, I was selected for the International Internship Pilot Program (IIPP) funded by Taiwan National Science and Technology Council (NSTC). My first internship (Dec 2024 – Feb 2025) was at the Neurodevelopment and Neuroepigenetics Lab, Graduate Institute of Brain and Mind Sciences, College of Medicine, National Taiwan University (NTU), where I worked on neuroscience projects involving data analysis and experimental research.

I was selected again for a second internship (June – Aug 2025) at NTU, focusing on advanced projects integrating medical physics, computational modeling, and neuroscience.

During both internships, I stayed in the international dormitory with roommates from different countries, including Martin Vidmar (Europe), Viggo Adel (Philippines), and Naveen Kumar (India). This cross-cultural experience enriched my personal and professional growth alongside my academic achievements.

About National Taiwan University (NTU)
National Taiwan University (NTU) is the top-ranked university in Taipei Taiwan, holding the 26th position in Asia and 63rd in the world. It is recognized for excellence across all disciplines, and being part of this prestigious institution during my internship was a valuable academic and professional experience.

Working with Brilliant Minds: My Lab Experience

One of the most rewarding parts of my internship in Taiwan was joining the Neurodevelopment

and Neuroepigenetics Lab at the Institute of Brain and Mind Sciences, National Taiwan University Hospital. Under the guidance of Professor Hsien-Sung Huang, I gained confidence in research and developed a stronger scientific mindset. I had the privilege to work closely with Ming-Yi Chou and Chih-Yu Lee, who provided valuable mentorship, while other colleagues—Pin-Yu Chen, Ting-Shue Chen, Hsin-Yu Cheng, Hsuan-En Chung, Yu-Chia Huang, Ke-Ching Guo, Yu-Hsuan Lee, Tzu-Yin Yang, De-Fong Huang, and Yu-Wei Kuo—made the lab feel like an academic family. Their cooperation, kindness, and dedication inspired me every day and further strengthened my passion for neuroscience research.

Project Title: Investigating Brain Regions and Neural Circuits Responsible for Social Behaviors Related to Autism Spectrum Disorders (ASD)
During my two research internships at the Institute of Brain and Mind Sciences, National Taiwan University, I worked on a project investigating how

Fig. Lab Colleagues with Professor Hsien Sung Huang brain activity is altered in autism spectrum disorders (ASD). I learned and performed key neuroscience techniques, including mouse perfusion, brain extraction, cryostat slicing, and immunofluorescence staining for c-Fos, a marker of neuronal activity. Using fluorescence microscopy, I imaged brain regions such as the prelimbic cortex (PrL), infralimbic cortex (IL), and hippocampal subfields (dHPC, vHPC).

The images were processed and analyzed with ImageJ/FIJI, where I delineated regions of interest and counted c-Fos–positive neurons. Statistical analysis with GraphPad Prism allowed comparisons between Wild-Type and Knockout mice with autism-related gene deletions.

Through this workflow ranging from experimental procedures to data analysis I contributed to uncovering region-specific brain activity changes linked to ASD. This project enhanced my technical skills, teamwork, and use of computational tools in neuroscience research.

Exploring Taiwan beyond the Lab .

- As part of my internship, I had the opportunity to visit **Intelligent Asia 2025 – Taiwan**, one of the leading exhibitions on advanced technology and innovation. It was a truly enjoyable and memorable experience with new friends, lab colleagues, and brilliant research minds from ESOE, National Taiwan University. We explored cutting-edge technologies in automation, robotics, AI, and sustainable industry—many of which I had never seen before. This visit not only expanded my knowledge but also created unforgettable moments of learning and collaboration.
- Friday was also a special day for another reason. All the Muslims in the community gathered together for Friday prayer. On that day, I felt a strong sense of unity, just like Eid. No matter where we came from— Pakistan, India, or elsewhere—everyone prayed and shared the same feelings. It made me realize the deep connection among Muslims around the world.
- It was especially exciting to meet Muslim students from Bangladesh, India, Russia, Indonesia, and Malaysia. One of the most interesting parts of my experience was the Friday night religious discussions. These discussions were open and informative, where people from different religions and countries like America, Taiwan, Pakistan, and India talked about Christianity and Islam.
- During my internship, I traveled across the capital city, Taipei, using the MRT and metro buses. It is a beautiful and organized city with modern transportation systems. I explored different areas and enjoyed the unique culture and lifestyle of Taiwan.
- At the end of the internship, we had a farewell gathering with students and researchers from different universities and countries, including the USA, Japan, Germany, France, Canada, India, and many more. It was a meaningful event where people with diverse mindsets came together to share thoughts, ideas, and experiences. This cultural and academic exchange created lasting memories and friendships, enriching my overall journey in Taiwan.
- A wonderful day was spent at the Taipei Zoo, one of the largest zoos in Asia, filled with fascinating animals and beautiful landscapes. The highlight of the visit was the Maokong

Fig. Religious discussion with international students

Gondola ride, offering breathtaking views of the city and surrounding mountains. It was a memorable experience that allowed me to appreciate the natural beauty of Taiwan alongside my academic journey.

- A memorable part of my fellowship was the cultural and exchange activities organized by IIPP. On January 17, 2025, during my first internship, all 118 selected students were invited to a fully sponsored cultural tour of Taiwan, offering insights into local traditions and a chance to connect with fellow interns. Later, on August 1, 2025, during my second internship, IIPP held a special exchange event where participants received program materials and engaged in meaningful networking and experience-sharing with other international students.
- Another memorable part of my journey was the annual dinners hosted by my internship supervisor, Professor Hsien-Sung Huang. The first dinner was arranged at a famous restaurant in Taiwan during my initial internship, where we enjoyed a wonderful meal with lab members and international fellows, ending the evening with a group photo to capture the moment. The second dinner took place during my second internship, once again bringing together the lab team and fellows in a warm and friendly atmosphere, making both gatherings truly special experiences.

The Rich and Diverse Culture of Taiwan

Taiwanese culture is a rich and vibrant blend of traditional Chinese heritage, indigenous influences, and modern global trends. Deeply rooted in Confucian values, respect for elders, family ties, and education are highly emphasized in daily life. Taiwan is also known for its colorful festivals such as the Lantern Festival and Dragon Boat Festival, which display traditional music, dance, and cuisine. Night markets are a hallmark of Taiwanese culture, offering a wide variety of local street foods, handmade goods, and a lively atmosphere. Additionally, the island embraces religious diversity, with temples dedicated to

Buddhism, Taoism, and folk deities found throughout the country. This unique mix of the old and new gives Taiwan its distinct cultural identity, where ancient traditions harmoniously coexist with modern lifestyles.

Achievements

- One of the proudest moments was being included in the official IIPP Handbooks during my both internships, which featured all 118 selected students. My name and journey were officially documented in this publication.
- Another proud moment in my journey was being featured on the official website of the Huang Lab at National Taiwan University, where I am currently conducting my internship. My name has been listed under the **Alumni People** section on the lab's website, recognizing my active involvement as a research intern. This acknowledgment reflects not only my selection but also my integration into one of Taiwan's leading neuroscience research teams. You can visit the lab's website at *www.huanglab.com.tw* and navigate to the People' section to view my name among the Alumni team members. It is a great honor to represent Pakistan and the University of the Punjab as well as PIEAS on such a global academic platform.
- The PSP (PIEAS Society of Physics) also recognized my achievement by including my name in their 2024 newsletter as an international fellowship holder.
- The Institute of Mathematics, University of the Punjab, proudly recognized my achievements at both time by featuring my selection for the prestigious NSTC International Internship Pilot Program (IIPP) on their official Facebook page. I am honored to represent the 2019–2023 batch as one of the 118 students selected globally, securing the 88th rank. The three-month internship at National Taiwan University, fully funded with a monthly stipend of TWD 30,000, reflects the unwavering support and guidance I received from the faculty, for which I am truly grateful. Must visit this page: (https://www.facebook.com/share/p1AP6kREPHn/)
- Dr. Abdul Qadeer Polytechnic Institute (DPI) College in Allahabad, where I completed my Intermediate also published a pamphlet featuring my success.

Future Goals and Directions

After completing my MS in Medical Physics at PIEAS, I aim to secure a fully funded PhD in Taiwan, focusing on medical physics related program. My first research paper, based on my internship project, will be published soon, marking the beginning of my academic contributions.

In the long term, I hope to settle in Taiwan, continue publishing impactful research, and contribute to international collaborations. My vision is to grow as a scientist and educator, sharing knowledge and building connections that benefit both Taiwan and Pakistan.

Ending Speech

My journey in Taiwan has been unforgettable full of learning, growth, and inspiration. I am deeply grateful to my mentor, lab colleagues, and the IIPP team for their constant support.

One thing I have learned is:

Dreams don't work unless you do

This is not the end, but the start of a new chapter. With hard work and faith, I believe greater achievements are waiting ahead Inshallah.

String Theory: Where do we stand today?

Hassaan Saleem, PhD

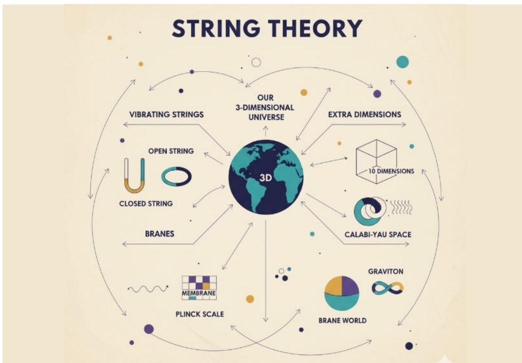
Theoretical Physicst and Ad. Professor at Univeristy of Albany

One of the major problems that many physicists have been working on for almost 50 years is to find a theory that describes all known fundamental particles and forces using a single framework. The solution to this problem is still elusive because it is really hard to come up with a theory that satisfies the following three reasonable criteria;1) It is quantum mechanical in nature 2) It describes the gravitational interaction 3) It gives finite values for quantities that should be finite (usually, these quantities are probabilities for certain processes to occur).

A theory that describes these criteria is called "quantum gravity". In 1970s, people realized that a formalism known as string theory seemed to satisfy all of these criteria. However, even after almost 40 years of what was called the "first superstring revolution", this theory is still not in its complete form. So, where is string theory today and what problems do we still need to solve to acheive its final form?

Basic idea and motivation: What is the basic idea behind string theory? At its core, string theory proposes a radical idea: the building blocks of the universe are not point-like particles, but one-dimensional strings. These strings vibrate at different frequencies, and the patterns of vibration correspond to the particles and forces we observe e.g. photons, electrons and quarks.

However, when people looked at the math of string theory, they concluded that this theory would have some problems (called anomalies). One of the easiest ways to get rid of these anomalies is to have ten spacetime dimensions. Since we only see four spacetime dimensions (we call these dimensions large dimensions), physicists proposed that the other six spacetime dimensions should be compactified to small spaces (so small that even our most advanced detectors today can't detect them). There are many ways to compactify these extra dimensions and the different ways to compactify them give rise to different types of physics that one sees in the large four dimensions. The original hope of string theorists was to find the right compactification for our universe, so that we can derive the physics that we see in our universe from the first principles. After decades of research, we have found out that it is very hard to find the right compactification for our universe from the plethora of possible compactifications allowed by string theory. The set of these possibilities is called the "string landscape". We have made a lot of progress to understand how to execute this whole program but there are also some challenges.



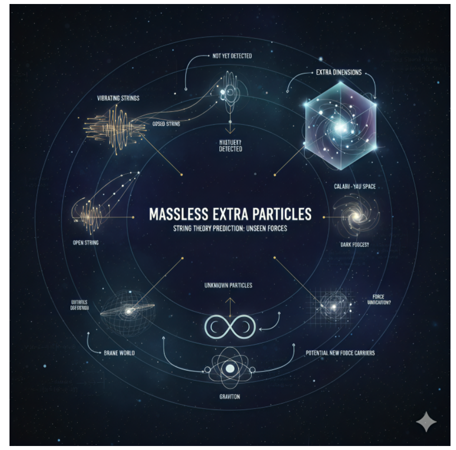
Scale Separation: A Crucial Puzzle: When we are compactifying the extra dimensions, a key challenge is achieving "scale separation" i.e. ensuring that the compact extra dimensions remain at a size much smaller than the four-dimensional spacetime we live in. In a perfect world, the physics of the extra dimensions would decouple cleanly from the physics we observe, meaning we wouldn't notice any leftover effects from them at large length scales. This is critical if string theory is to reproduce the successes of the Standard Model (a very successful theory in particle physics) while still incorporating quantum gravity.

However, scale separation is notoriously difficult to achieve in string theory constructions. Many simple models tend to have the size of extra dimensions not so far below than the size of our large dimensions, potentially leading to unwanted effects. A useful construction that physicists have found in string theory that achieves scale separation is called DGKT construction and several other people have worked on this construction. There are even some arguments to show that scale separation may be impossible to acheive in certain scenarios. Finding mechanisms that generate scale separation is an ongoing area of active research.

Swampland program: Not everything goes with gravity: Can every theory that is compatible with gravity at low energies continues to be compatible at arbitrarily high energies? This is a question that would be easy to answer if we could see how a particular theory behaves at high energies, but this behavior isn't easy to deduce. However, can you look at the low energy description of a theory and tell if it would be consistent with gravity at high energies? This question started a whole field of research called the swampland program. In this line of research, researchers have formulated some properties (called swampland conjectures) such that if the low energy theory has those properties, then they can't be compatible with gravity at high energies. Such theories are said to be in the "swampland".

This program has deepened our understanding of the structure of quantum gravity. For example, we have learned that in any possible theory of quantum gravity, gravity should always be the weakest force (this statement comes from a swampland conjecture called the "Weak gravity conjecture"). The current swampland research focuses on minimizing the number of independent swampland conjectures by finding relationships between the conjectures that we have.

An additional idea that has come out of this program is the idea of dark dimension. This idea uses a single extra dimension and tries to relate the existence of dark matter (extra matter that the universe seems to have) and cosmological constant (an in-built energy

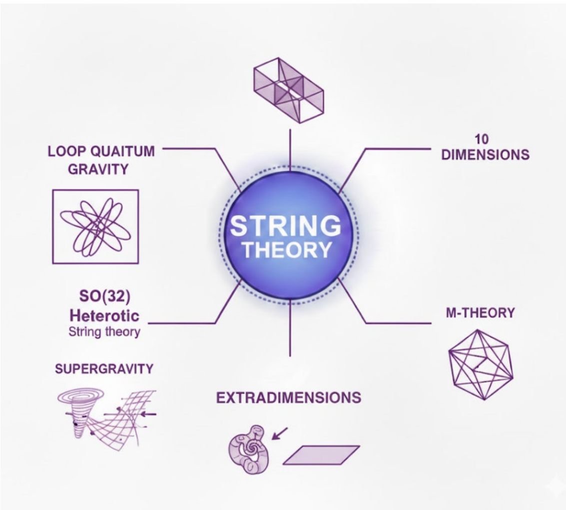


in spacetime that is hypothesized to cause the expansion of the universe) - which is also called dark energy. This idea is still in its infancy, and we still need to see what it would lead us to.

Moduli Stabilization: Avoiding the massless: When we compactify the extra dimensions, we get some parameters that govern the shape of these extra dimensions. These parameters are called moduli and these moduli can give rise to extra massless particles. These extra massless particles would give rise to extra long range forces (like gravity and electromagnetism) which we don't observe in our universe. If we can't get of these massless particles, they would be disastrous for string theory. Therefore, these particles should be made massive by some mechanism in string theory. The candidates for this mechanism are known as "moduli stabilization" mechanisms. A lot of progress in understanding moduli stabilization was made in the early 2000s with KKLT scenario (named after four physicists who proposed it) being the most famous study.

The problem of moduli stabilization is tightly tied to other deep questions, like whether string theory can produce universes with a small positive cosmological constant (like our accelerating universe) or whether it leans toward producing universes with negative or zero cosmological constants. It turns out that producing a universe with a positive cosmological constant it notoriously hard (at least by using the methods that we have to probe some limiting cases in string theory) and it is possible that we would need new methods to solve this problem. There are some studies that obtain a positive cosmological constant from string theory, but those studies either seem to be riddled with problems when it comes to details (like the KKLT scenario), or the give a cosmological constant that is too small. They may also have some other unresolved issues (e.g. the existence of some singularities). Obtaining a small positive cosmological constant is one of the holy grails of string theory research.

String Universality: Are strings inevitable? A profound idea that has emerged in string theory research is "string universality" i.e. the notion that all consistent quantum theories of gravity might be realized as different limits of string theory. In other words, string theory may not be just 'a' theory of quantum gravity; it could be the "only" mathematically consistent one.



This is a bold claim. To show that string universality is a fact, we need to show that every theory compatible with gravity that we can write down, which is accurate at low energies can also be achieved from some theoretical construction in string theory. People have shown that this fact is true in 10, 9, and 8 dimensions. Therefore, any 10, 9 or 8 dimensional theory that is compatible with gravity is string theory in disguise. We still haven't shown that this universality exists in 7 or lower dimensions but there are some promising ideas that people are working on. If we are able to show that string universality exists for possible number of dimensions (from 2 to 10), then it would be fully justified to say that "string theory is the only game in town".

Conclusion: The quest continues String theory remains a grand, unfinished adventure. It is one of the most ambitious attempt humanity has made to weave together the deep laws of the cosmos into a single framework, linking gravity, quantum mechanics, and particle physics.

It may yet prove to be the elusive unified theory, or it may serve as a stepping stone toward an even deeper understanding. Either way, the quest itself is reshaping our understanding of the universe and our place in it.

Physics and Engineering: Inseparable Pillars of Innovation

Dr. Muhammad Yousaf Hamza
Deputy Chief Engineer (R), PIEAS

Back in the late 1980s, when I was a student at UET Lahore, engineering students were often seen gathered at the university canteen, around the tables with cups of tea, coffee, snacks, and lighter talks. These casual get-togethers often turned into funny arguments, with each student proudly supporting his own field of engineering — and teasing the others in light mode. It was all just for fun and showed how close we were and how touchy we were about our fields.

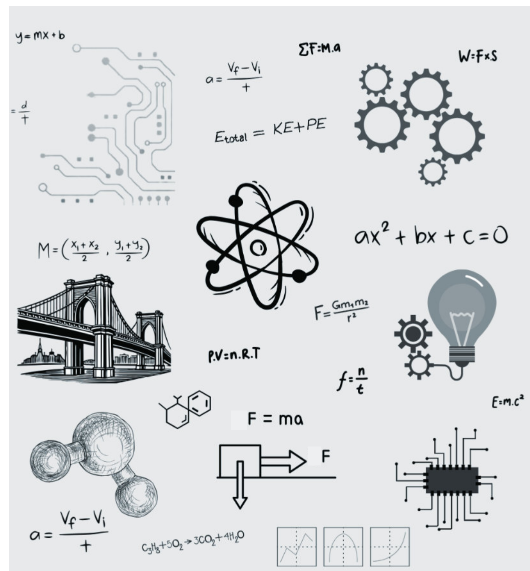
Usually, a mechanical engineering student would start: "We make the machines that build everything else. You are just machinist. That means we're the real bosses." A civil engineering student would smile and say: "Ahaa, without me constructing the labs, roads, and buildings, where would you even build or place your machines?" Then the electrical engineering student would join in: "Good one, but let's be honest — without electricity, you'd all be sitting in the dark. Who do you think powers your labs and rooms? What can you do in darkness?" Next came the chemical engineering student, calmly sipping tea: "You're all missing the point, without chemical engineering, there'd be no fuels to drive industries, and no essential medicines to ensure survival, no fertilizers to feed the world, and certainly no caffeine in this tea. You're just playing around — I'm doing real engineering." After a brief silence, the materials engineering student, who had been listening patiently, finally spoke — softly, yet leaving the others speechless: "No materials, no anything. That's it."

In those days, computer and software engineering weren't well-known as separate branches. But if they were, the talk might have gone like this: A computer engineering student would say: "And who made the hardware and control systems for your machines and electricity? That's computer engineering." Then the software engineering student would walk in late, looking sleepy and say "Sorry I'm late — I was fixing bugs till 4 a.m. Just saying, all your hardware is useless if the software crashes." After all the teasing, the civil engineer might say with a smile: "Can't we just agree that every engineering branch is important?" And the software engineer, already checking the Wi-Fi, would say "Yeah... as long as the internet works."

Back then, as BS Engineering students, we didn't really deeply know the most important fact *"No Physics, No Engineering."*

Holding a BS in Electrical Engineering degree and having served in various physics related positions, including Head of the Department of Physics and Applied Mathematics, I was invited to write an article titled 'Physics and Engineering: Inseparable Pillars of Innovation'.

Engineering is often defined as the practical application of science and mathematics to solve real-world problems, and among all scientific disciplines, physics stands out as the most essential. It provides the core principles that underlie every engineering field. From classical mechanics to modern quantum theory, physics forms the theoretical bedrock of engineering innovation.



In ancient times, the boundaries between science, philosophy, and engineering were blurred. Civilizations like the Egyptians and Mesopotamians constructed architectural marvels such as pyramids and ziggurats using empirical methods, long before the formalization of scientific principles. The scientific revolution of the 16th and 17th centuries marked a pivotal shift. Pioneers like Galileo, Newton, and Watt laid down the laws of motion, mechanics, and thermodynamics, elevating engineering from an empirical craft to a disciplined science rooted in physics, mathematics, precision and predictability.

Each classical branch of physics corresponds to a core engineering discipline. Mechanics forms the solid foundation and plays a crucial role in civil and mechanical engineering; thermodynamics drives innovations in energy systems; electromagnetism, developed through the work of Faraday and Maxwell, underpins electrical and computer engineering; and optics supports fields like optical engineering. The transition from classical to modern physics has opened new engineering frontiers. Einstein's theory of relativity is crucial for technologies like GPS.

In the current era of rapid technological evolution, where technological demands are greater than ever, the partnership between physics and engineering is not just important — it is indispensable — artificial intelligence, renewable energy, nanotechnology, quantum computing, smart infrastructure, and space exploration, the role of physics becomes even more critical. These innovations rely on a precise understanding of how the physical world behaves. These emerging technologies would not exist without the insights provided by modern physics. This fact leads to say, physics is the "backbone of engineering". The modern engineering development is possible only through a deep understanding of modern physics. It allows engineers to model and simulate real-world systems before they are built. With tools based on physical laws, engineers can predict how a design will perform under various conditions, reducing the cost and time of prototyping and improving overall performance. Every decision — from material selection to energy efficiency — relies on physical laws.

Without Physics, Engineering Can't Succeed

Engineering and physics share a deeply interdependent, symbiotic relationship — neither can thrive without the other. Without physics knowledge, engineering would be reduced to guesswork and trial-and-error, lacking the predictive power needed to develop reliable, safe, efficient, and effective solutions. It means engineering without physics is like building on sand: unstable, unpredictable, and potentially dangerous.

For example, without Newtonian mechanics, civil and mechanical engineers couldn't calculate forces or load-bearing capacities. Chemical plants designed without knowledge of heat transfer would be vulnerable to explosions. The development of electronics, such as smartphones, would be impossible without understanding electron flow, signal processing, and electromagnetism.

Disastrous consequences are associated with engineering without proper consideration of physics. History is filled with engineering failures that were ultimately caused by ignoring or misunderstanding physical laws. For example, the Tacoma narrows bridge collapse (1940) due to a lack of understanding of resonance and aerodynamic; space shuttle challenger's explosion (1986) due to miscalculations related to temperature effects on materials; that same year the Chernobyl nuclear meltdown — one of the worst technological catastrophes in the history — occurred largely due to a disregard for thermal dynamics and reactor physics. These tragedies are powerful reminders that following the physics knowledge is a "MUST" requirement for responsible engineering. In short, physics empowers engineers to move beyond trial-and-error methods, ensuring that their designs are not only functional but also optimal, safe, reliable, and innovative.

Tacoma narrows bridge collapse

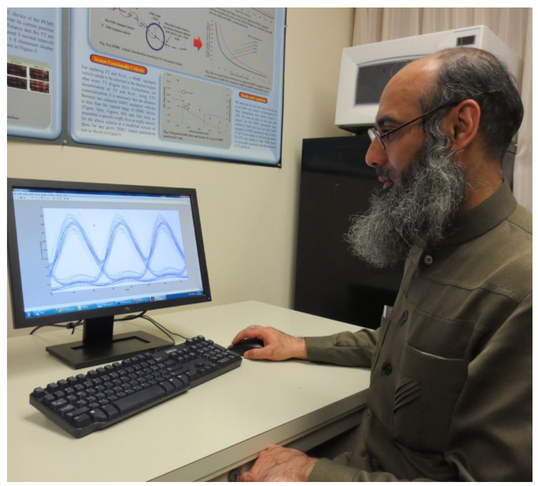
This interdependence goes both ways. Physics also relies heavily on engineering to test, apply, and validate its theories. Engineering enables the construction of advanced instruments like the Large Hadron Collider (LHC), which was designed to answer some of the most fundamental questions in physics. Tools like finite element analysis, high-performance computing, and automation systems — all developed by engineers — allow physicists to simulate and analyze complex phenomena. Without engineering, much of experimental and computational physics would be impractical or impossible. In short, engineering would not exist without the insights of physics, and physics finds many of its practical validations through engineering. Without physics, there can be no true engineering — and without engineering, innovation stands still.

Due to its importance, in both education and research, the link between physics and engineering is emphasized. Most engineering curricula include physics courses in the first years, ensuring students develop a strong scientific foundation. In research, collaboration between physicists and engineers is common, especially in fields such as space exploration (NASA, ESA), particle physics (CERN), renewable energy systems, artificial intelligence and robotics, biomedical device development, the list goes on.

The links of Physics with some specific engineering fields are provided below:

The link between physicists and electrical engineers is foundational and deeply intertwined, especially in the modern development of electronics and electrical technologies. Physicists lay the groundwork by discovering and explaining fundamental physical principles electromagnetism (Maxwell's equations), quantum entanglement, superposition, photovoltaic effects, which electrical engineers later apply to real-world technologies, hardware implementation, error correction circuits, fiber optics, lasers, optical sensors, solar panels, smart grids, power electronics, signal processing and radiofrequency engineering to design antennas, transformers, and integrated circuits. Example: The discovery of the photoelectric effect (by Einstein) led to the development of solar panels (engineered by EE). The synergy between the two has driven nearly every major breakthrough in electronics, communications, energy systems, and computing.

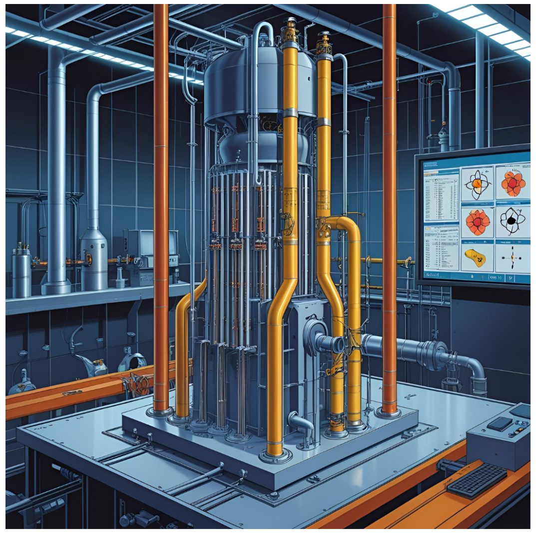
The link between physicists and mechanical engineers is deeply rooted, forming the backbone of innovation in today's mechanical field. Physicists developed Newtonian mechanics, thermodynamics, fluid dynamics, laser-material interaction, mechanical engineers apply these principles to design machines, engines, vehicles, HVAC systems, stress and deformation analysis, heat transfer simulations, vibration and dynamics studies, 3-D printing, CNC machining, heat treatment, failure analysis, aerospace components, actuators, design of nano-sensors and MEMS devices. Tools like ANSYS, COMSOL, and MATLAB rely heavily on physics-based modeling.



The role of physics in chemical engineering is marvelous, that provides deep insight into atomic and molecular behavior, enabling innovations in materials and reactions, thermodynamics, electrochemistry, catalyst modeling, molecular-level interactions, and ion transport. Chemical engineers apply physics knowledge to design scalable, safe, and efficient processes and products. Together, they drive innovation in energy, nanotech, pharmaceuticals, environmental engineering, and advanced materials, to model reaction kinetics and heat/mass transfer, water purification membranes and energy storage devices, material synthesis, electrolyte design, cell assembly etc.

The link between physicists and metallurgical engineers is crucial for the modern development of metallurgy, especially as the field evolves toward advanced materials, nanotechnology. Physicists study atomic bonding, electron configurations, phase transformations, x-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), electron/ion transport theory, solid-state and low-temperature physics etc. This theoretical foundation helps metallurgical engineers to design and optimize alloys, analyze microstructures, investigate defects, monitor quality control, predicting corrosion and fatigue, lightweight heat-resistant alloy development, thin films, surface treatments, protective coatings, fabrication and stabilization of advanced materials, biomedical implants. Tools like density functional theory (DFT) — developed by physicists — are now widely used in metallurgy to model materials behavior before fabrication.

The link between physicists and nuclear engineers is very important. Nuclear physicists study and model nuclear structure and decay, radioactivity, fission and fusion reactions, neutron transport, chain reactions, critical mass and reactivity, behavior of uranium, plutonium, thorium at the atomic level, interaction of radiation with matter, probabilistic modeling of core behavior, study of long-term radioactive decay, plasma physics, magnetic confinement, interaction of radiation with detectors, new isotopes and medical radionuclides. Nuclear engineers use this knowledge to design reactors, control radiation, optimize nuclear fuel cycles, ensure safety in nuclear systems, build stable and efficient reactors, develop cooling systems and shielding, manage reactor operations and shutdown systems, fabricate nuclear fuel (pellets, rods), analyze radiation damage in structural materials, improve fuel efficiency and lifespan, emergency cooling systems, reactor vessel design, fuel injection, heat removal, calibration, shielding, and system integration. Their synergy drives progress in nuclear power, fusion energy, medical isotopes, radiation safety, national security and nonproliferation. The concept of neutron moderation, discovered by physicists, is essential to nuclear reactor design managed by engineers.



Physics-guided nuclear reactor design showing fuel rods, cooling systems, neutron paths, and radiation control

Physicists and civil engineers are closely linked through their shared reliance on the principles of physics to understand and manipulate the physical world. Physicists explore fundamental laws — such as gravity, motion, and energy — that civil engineers apply to design and construct safe, efficient structures like bridges, buildings, and dams. For instance, knowledge of material properties, force distribution, and structural dynamics, all grounded in physics, is essential for civil engineers to ensure stability and durability. This collaboration between theoretical insight and practical application forms the backbone of modern infrastructure development.

Physics and aerospace engineering are deeply interconnected, as the principles of physics form the foundation of how aircraft and spacecraft operate. Concepts such as aerodynamics, propulsion, thermodynamics, and Newton's laws of motion are essential in designing and analyzing flight systems. Aerospace engineers rely on physics to understand how forces act on a vehicle in air or space, how materials behave under extreme conditions, and how energy patterns are formed during flight. Without physics, the development of efficient, safe, and advanced aerospace technologies would not be possible.

Physics and optical engineering are closely linked through the study and application of light. Optical engineering relies on the principles of optics — a branch of physics that explores the behavior and properties of light — that helps the optical engineers to develop devices such as lenses, microscopes, lasers, and fiber-optic systems. Understanding wave behavior, refraction, diffraction, and quantum effects enables optical engineers to manipulate light for a wide range of applications, from telecommunications to medical imaging. Without the foundational theories provided by physics, modern optical technologies would not exist.

Physics and computer engineering are closely connected through the underlying physical principles that make modern computing possible. Concepts from physics, such as electromagnetism, quantum mechanics, and semiconductor theory, are essential for designing and building electronic components like transistors, processors, and memory devices. Computer engineers apply this knowledge to develop faster, smaller, and more efficient hardware. Additionally, physics helps in understanding signal behavior, heat dissipation, and energy consumption in computing systems. This foundation allows computer engineering to push the boundaries of technology and innovation.

Biomedical engineering uses principles of fluid dynamics and electromagnetism in the development of prosthetics, imaging systems, and diagnostics. Environmental engineering depends on physics for modeling pollution dispersion, energy transfer, and climate systems. Quantum engineering, an emerging field, directly applies quantum physics to develop next-generation sensors, computers, and communication networks. Quantum physics is revolutionizing computer engineering through quantum computing and cryptography.

Physics powering biomedical imaging and diagnostics through electromagnetism and fluid dynamics

The link between physics and software engineering lies in the application of logical thinking, mathematical modeling, and problem-solving skills that are fundamental to both fields. Physics contributes through simulations and computational models to solve real-world problems. Software engineering primarily deals with writing and managing the code to run simulations to validate physics investigations. In areas like scientific computing, game development, and virtual reality, software engineers often rely on physical principles to create realistic and accurate systems. Thus, physics provides the theoretical backbone for many software applications that model or interact with the physical world.

Choosing Between Physics and Engineering: What's Right for You?

Deciding for a BS degree in Physics or Engineering branch is a big step, and the right choice depends on your interests, mindset, and career goals. Both paths offer rewarding opportunities but differ in focus and applications.

If you're driven by curiosity about how the universe works — on the most fundamental level — Physics might be your path. Physics is about uncovering the laws of nature, from quantum particles to galaxies. It suits those who enjoy deep theoretical thinking, and asking "why" and "how" at the most basic level. Careers in physics often involve research, academia, or cutting-edge fields like plasma physics, astrophysics, nanotechnology and many more. Many physics careers require postgraduate studies (Master's / PhD).

On the other hand, if you're more interested in applying scientific knowledge to develop practical solutions and models, engineering may be a better fit. Engineers design, build, and improve real-world systems — from bridges and machines to circuits, software, and medical devices. If you enjoy hands-on projects, solving tangible problems, and seeing the immediate impact of your work, engineering offers structured roles across industries like energy, healthcare, aerospace, and more. Engineering is also known for its strong job market and diverse career paths. To summarize, choose physics if you're passionate about fundamental science, theoretical questions, and long-term research; choose engineering if you're excited by real-world impact, innovation, and building practical solutions.

Is there any overlap between the two? Yes. The above written stuff shows the engineering fields are deeply rooted in applied physics.

Don't Worry if Physics is not Your First Choice

If you are currently enrolled in a BS Physics program but feel that physics may not be the right fit for you — perhaps you originally wanted to pursue engineering but couldn't secure admission due to high merit requirements, or you were **a pre-medical student** who ended up in physics as a second choice — don't worry. Stay committed to your BS Physics, work hard with passion and determination, and complete your degree.

Physics graduates are highly valued in both engineering and medical-related fields because they possess strong analytical thinking, problem-solving skills, and a solid grasp of scientific principles. The strong background in physics opens the door to a wide range of rewarding career opportunities, and it often allows for a relatively smooth transition into engineering or medical fields.

Your physics education is not a setback — it's a strong foundation for success in diverse professional areas. A brief picture is provided below.

Physics provides a strong foundation for transitioning into various engineering disciplines, such as electronics, computer engineering, aerospace engineering and more. Another important field is nuclear engineering. BS Physics graduates can excel in nuclear engineering in the fields such as nuclear reactors, radiation safety, fusion energy research, nuclear power generation, radiation safety, nuclear medicine, and advanced reactors, etc.

Physics plays a vital role in modern healthcare, particularly in technology-driven areas. Graduates with a physics background can pursue careers in medical physics, a field in high demand at hospitals and cancer treatment centers for its applications in imaging, diagnostics, and radiation therapy. Another promising path is biomedical engineering, where knowledge of mechanics, electromagnetism, and thermodynamics contributes to design and manufacture of medical devices and systems. Radiology and clinical research also present exciting opportunities, involving advanced imaging technologies or contributing to innovations in health diagnostics and medical technologies.

By pursuing a Master's or PhD in these emerging interdisciplinary fields, you can position yourself for exciting opportunities across teaching & research institutions and the industry sector.

The reverse transition is also possible — engineers with a strong inclination toward theoretical concepts may find their true passion lies in physics. I share this from my personal experience. Originally holding electrical engineering degree, my growing passion for the fundamental laws of nature led me to shift toward physics — earning an M.Phil. in Quantum Optics followed by an MS/PhD in Lasers and Fiber Optics.

With dedication and hard work, I taught a wide range of physics courses — from fundamental concepts to advanced topics. I also led and contributed to numerous theoretical and computational physics research projects, and eventually served as Head of the Department of Physics and Applied Mathematics at PIEAS, Islamabad. This transition proved to be not only professionally rewarding but also deeply satisfying on a personal level.

To sum up: physics is fundamental to engineering. Without a solid understanding of physics, reliable engineering is not possible. Both are vital for driving human progress and shaping a better, safer, and more technologically advanced future.

The Star that Brought Humanity Down to Earth!

Dr Salman Hameed

Astrophysicist, Prof. at Hamphire College and Founder of Kainat Studios

Blame the star. Humans had just started to recover from the realization that the Earth moves around the Sun and not the other way around. The Polish priest Copernicus, building on observations and models of other medieval scholars, like Nasir al-Din al-Tusi (1201-1274 C.E.) and Ibn al-Shatir (1304-1375 C.E.), had taken the audacious step of making the Earth move around the Sun.

He knew what he was doing to the self-esteem of fellow human beings. He announced the demotion of the Earth from his deathbed in 1543 C.E. But this demotion also meant that our Sun was just like other twinkling pinpoints of light. It just happened to be close to us to appear big and extremely bright, especially during the day-time.

We took the demotion on the chin. We still thought that the Sun was at the centre of the universe. Even though we were stuck in the gravitational well of our star, this was still not a bad deal for us. We could still be important riding on the Sun's coattails. This was working well. But then this all changed almost exactly a hundred years ago. In October 1923, Edwin Hubble used the 100-inch Mount Wilson Observatory in California to detect a star that changed its brightness in a fuzzy cloud known at the time as Andromeda nebula.

You can see yourself this fuzzy Andromeda. In fact, Persian astronomer Abd al-Rahman al-Sufi (903-986 C.E.) had noted this fuzzy patch in his beautifully illustrated The Book of Fixed Stars (kitāb suwar al-kawākib) written around 964 C.E.

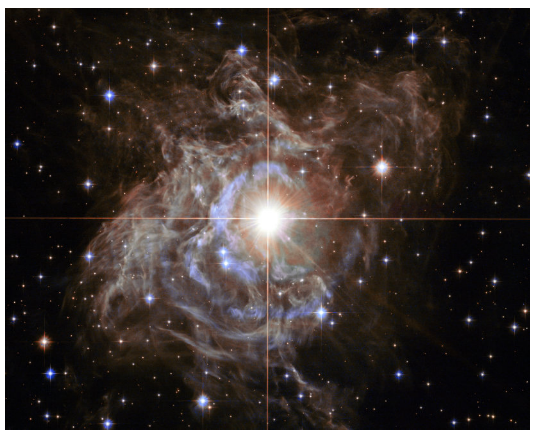
Later, telescopes revealed that this was a collection of stars. And there were others like it, but too faint to be visible to the naked eye. But how big and how far away were these "spiral nebulae"? Prominent Harvard astronomer, Harlow Shapley. and many others, believed that these were all part of the Milky Way, and that the Milky Way was the entire universe. Some, like Edwin Hubble, suspected that these "spiral nebulae" were "island universes" similar to the Milky Way itself. They looked small and fuzzy because they were at incredibly large distances, distances unimaginable at the time.

These were two very different views of the universe. One would turn out to be right and the other wrong. Science can be cruel that way.

It all came down to one star and the incredible work of a Henrietta Leavitt.

Leavitt was a 'computer' at Harvard College Observatory in the early 1900s. Harvard computers were a group of skilled women who analyzed astronomical data taken from photographic plates on various telescopes. Henrietta Leavitt studied stars that varied in brightness in a predictable way.

She identified a particular group of stars called cepheid variables. She studied 1777 such stars. Of particular interest were 25 that could be seen from the southern hemisphere. These were all part of a collection of stars called the Small Magellanic Cloud. Crucially, this meant that all twenty five stars were all located roughly at the same distance from us, allowing her to identify their brightness relative to each other.



RS Puppis, one of the brightest known Cepheid variable stars By NASA, ESA, and the Hubble Heritage Team

She discovered that not only do these stars vary in brightness over a period of time, but their brightness is related to their period. For example, a star that varies in brightness every 5 days is a little fainter than the one that varies every 12 days. This came to be known as Period-Luminosity relation or Leavitt's Law.

This observational insight turned out to be one of the most important in astronomy. Leavitt had discovered a standard candle that can help measure distances to far-off stars.

The foundation of this is relatively simple. You can think of lighted candles during load-shedding at night. If the candle is close to you, it will look brighter. Dimmer, if it is farther away. Since we intuitively know the brightness of a flame, we can guess the distance to the candle based on how bright it appears.

In cepheids, Henrietta Leavitt had found a candle in the night sky. If you can measure the brightness cycle of a cepheid star, you can figure out how bright it should be. If it appears fainter in the sky then that means that it is farther away. We also know that if you double the distance, the light fades away four times. If you triple the distance, the light fades away nine times (for science nerds, this is called inverse square law). Crucially, this allows astronomers to calculate distances to stars.

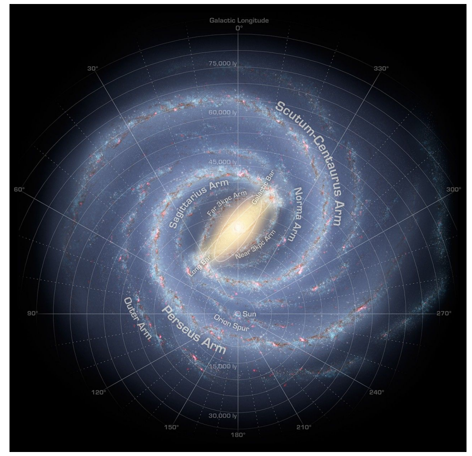
A cepheid variable star could then resolve the debate over the nature of spiral nebulae.

Almost a hundred years ago, in October 1923, Edwin Hubble found the first cepheid star in Andromeda. The cycle of brightening and dimming revealed that this cepheid was at an enormous distance, far away from the Milky Way. Therefore, Andromeda was a galaxy just like our own. It only looks faint and small because of its enormous distance. Today we know that it isover two million light years away!

Hubble had fundamentally altered the view of our universe. We were just recovering from the demotion of the Earth from the center of the universe. Now we discovered that the universe was also unimaginably big. When the news of Edwin Hubble's new distance estimate to Andromeda reached Harlow Shapley, he is known to have commented that it "destroyed my universe", underlining the fact that the universe does not necessarily care about our cherished ideas.

Henrietta Leavitt surely deserved a Nobel prize for making one of the most important discoveries in astronomy. Edwin Hubble even nominated her for the award in 1925. Unfortunately, she had already passed away in 1921, at a relatively young age of 53, and the award is not given posthumously.

Today we know that there are more than a hundred billion galaxies in the known universe. But so what? The Milky Way is still our galaxy, and we must surely be still be at its centre. But now we have to pin some blame on Harlow Shapley. Like a good scientist, he picked up the pieces of his destroyed universe and went on to use cepheids (and other type of variable stars) to help determine the shape of the Milky Way and our position in it. He found that, instead of being at the centre of the Milky Way, the solar system is floating in the outskirts of the galaxy. Today we know that the Sun is part of an inconspicuous spiral arm, located about 30,000 light years from the Milky Way centre.



Credit: NASA/JPL-Caltech/R. Hurt (SSC/Caltech)

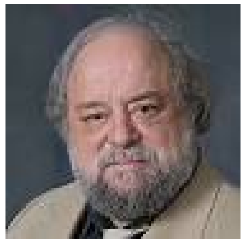
We cannot (yet) go outside of the Milky Way to take a selfie. However, we can look at the spiral arms of Andromeda galaxy and imagine a Sun-like star there with orbiting planets and perhaps with lifeforms thinking about their place in the universe. In the close-up, we only see noise - dots spread throughout the image. But each dot here is a star. We cannot see it, but we expect planetary worlds orbiting around each of these dots. And some of those worlds may even have species that can figure out their own insignificance in this vast cosmos.

Homo sapiens, located on a rocky world in the outskirts of Milky Way, are beginning to understand the immensity of our universe. For this they have to thank a type of star that varies in brightness, and a brilliant woman who figured out how to use this variation to measure distances to faraway galaxies.

Viva homo sapiens, viva curiosity!

Latest Awards and Recognitions

John Cardy



Alexander Zamolodchikov

Breakthrough Prize in Fundamental Physics

Often called the "Oscars of Science," the Breakthrough Prize in Fundamental Physics honors profound contributions that lead to new insights into the deepest questions of the universe. It recognizes major advances in fields like quantum mechanics, relativity, and cosmology, rewarding discoveries that reshape our understanding of fundamental physical laws.

In 2024, John Cardy of All Souls College, University of Oxford, and Alexander Zamolodchikov of Stony Brook University were honored for their groundbreaking and enduring contributions to statistical physics and quantum field theory. Over the course of their illustrious careers, both have reshaped the landscape of theoretical physics, providing deep insights that extend far beyond particle physics.

Cardy is especially known for his foundational work in conformal field theory and its application to critical phenomena in two dimensions, including the celebrated "Cardy formula," which links field theory to black hole entropy and statistical mechanics. His work has helped establish powerful connections between physics, probability theory, and geometry.

Alexander Zamolodchikov is revered for pioneering work that introduced exact solutions and integrable structures into quantum field theory, revolutionizing the way physicists understand two-dimensional models. His development of the c-theorem and exact S-matrix formulations opened new paths for understanding both equilibrium and non-equilibrium phenomena in quantum systems. Together, Cardy and Zamolodchikov have expanded the utility of quantum field theory to describe emergent phenomena in systems ranging from magnets and superconductors to quantum gravity and black hole thermodynamics. Their insights continue to inspire both physicists and mathematicians, demonstrating the unifying power of theoretical physics across diverse domains

Mikhail Ivanov

New Horizons in Physics Prize

The New Horizons in Physics Prize is awarded to early-career physicists who have already made significant breakthroughs. It acknowledges rising stars whose work shows exceptional promise in advancing fundamental physics, from

from black hole dynamics to the large-scale structure of the universe.

In 2024, Michael Johnson of the Center for Astrophysics | Harvard & Smithsonian and Alexandru Lupsasca of Vanderbilt University were recognized for their pioneering theoretical work on black hole photon rings—narrow, bright features predicted to form by light orbiting the event horizon of a black hole. Their research has provided a detailed understanding of the sub-structure and universal properties of these rings, revealing how

Oliver Philco

Marko Simonović

they encode key information about the geometry of spacetime and black hole spin. By outlining how future interferometric arrays, such as extensions of the Event Horizon Telescope, could detect these features, Johnson and Lupsasca have opened new possibilities for testing general relativity and black hole physics with unprecedented precision.

Among the other honorees were Mikhail Ivanov (Massachusetts Institute of Technology), Oliver Philcox (Columbia University and the Simons Foundation), and Marko Simonović (University of Florence), recognized for their pioneering work on the large-scale structure of the universe. Their research has produced powerful theoretical frameworks and statistical tools that enable cosmologists to extract fundamental physical parameters such as neutrino masses and the nature of dark energy from galaxy surveys with unprecedented precision. In the field of planet formation, Laura M. Pérez (Universidad de Chile), Paola Pinilla (University College London), Nienke

Alexandru Lupsasca

Michael Johnson

van der Marel (Leiden Observatory), and Til Birnstiel (Ludwig-Maximilians-Universität München) were jointly honored for their groundbreaking discovery and modeling of dust traps in protoplanetary disks. These structures, first predicted and later confirmed through observations, have helped resolve a key question in planetary science: how tiny dust grains grow and accumulate into planetesimals. Their work has fundamentally advanced our understanding of how planetary systems, including our own, form from disks of gas and dust surrounding young stars.

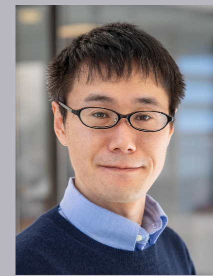
Dirac Medal and Prize (ICTP)

Named after the legendary physicist Paul Dirac, the Dirac Medal is awarded by the Abdus Salam International Centre for Theoretical Physics (ICTP) for outstanding contributions to theoretical physics. It particularly highlights achievements that deepen our understanding of quantum mechanics, field theory, and fundamental interactions.

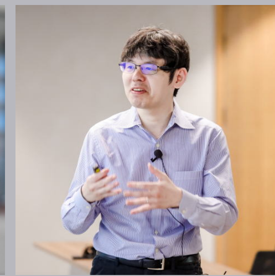
In 2024, Marina Huerta (Instituto Balseiro and CONICET), Horacio Casini, Shinsei Ryu, and Tadashi Takayanagi were jointly honored for their profound contributions to theoretical physics, with a shared focus on quantum entropy and the role of

Marina Huerta

Horacio Casini



Shinsei Ryu



Tadashi Takayanagi

entanglement in quantum field theory. Marina Huerta and Horacio Casini, both based in Argentina, have developed powerful theoretical frameworks that use quantum entanglement entropy as a tool to probe the structure of quantum field theories. Their work has led to general and far-reaching results, such as new proofs of the c-theorem and insights into the universal behavior of entanglement in relativistic quantum systems, helping to clarify fundamental aspects of quantum information in high-energy physics.

Shinsei Ryu and Tadashi Takayanagi, working at the intersection of string theory and quantum information, are renowned for uncovering a striking correspondence between quantum entanglement and

Greg Hammett

Bill Dorland

the geometry of spacetime. Their celebrated Ryu-Takayanagi formula provides a holographic interpretation of entanglement entropy, linking it to the area of minimal surfaces in higher-dimensional gravitational theories—a breakthrough that has deepened our understanding of the AdS/CFT correspondence. Together, the work of these four scientists has transformed entanglement from a quantum curiosity into a central organizing principle for quantum gravity, field theory, and beyond, marking a major shift in how physicists conceptualize the quantum structure of reality.

James Clerk Maxwell Prize for Plasma Physics

Awarded by the American Physical Society, the James Clerk Maxwell Prize honors exceptional achievements in plasma physics, recognizing both theoretical and experimental advances with wide-reaching applications—from fusion energy to astrophysical plasmas. In 2024, Gregory W. Hammett of the Princeton Plasma Physics Laboratory and Bill Dorland of the U.S. Department of Energy received the prize for their groundbreaking work on kinetic plasma turbulence.

Gregory Hammett, a leading figure in fusion research, has made significant contributions through the development of gyrokinetic models that describe the complex dynamics of charged particles in magnetically confined plasmas. His theoretical and computational innovations have been instrumental in improving predictions of turbulent transport in fusion devices like tokamaks, bringing the field closer to realizing practical nuclear fusion as a sustainable energy source.

Bill Dorland, a prominent plasma physicist and policy leader within the Department of Energy, has similarly made transformative contributions through both his scientific research and leadership. Formerly a professor at the University of Maryland and director of its Institute for Research in Electronics and Applied Physics, Dorland played a central role


Robert Klanner **Eckhard Elsen**

in developing high-performance simulations of plasma turbulence, notably through the GYRO and GS2 codes—tools that have become standards in the field. His work integrates theoretical insights with large-scale numerical simulations, enabling deeper understanding of turbulence in both laboratory and astrophysical plasmas.

W.K.H. Panofsky Prize in Experimental Particle Physics

The Panofsky Prize celebrates excellence in experimental particle physics. It is awarded to physicists whose work has led to significant discoveries about the fundamental particles and forces that make up the universe, especially through innovative experimental techniques or instrumentation. In 2025, Robert Klanner and Eckhard E. Elsen were honored for their seminal contributions to experimental particle physics through their pioneering work at the HERA (Hadron-Elektron-Ringanlage) accelerator at DESY, Germany's leading center for high-energy physics. Robert Klanner, renowned for his work in developing silicon detectors, played a critical role in enhancing the precision of particle tracking technologies. These innovations proved essential for experiments at HERA, where unprecedented collisions between electrons and protons allowed scientists to probe deep into the internal structure of the proton. His expertise in detector development laid the groundwork for techniques that have since become standard at modern colliders.

Eckhard E. Elsen, an accomplished physicist and former research director at CERN, was instrumental in the design and analysis of HERA experiments that explored the proton's structure at very small distanc

e scales and high energies. His leadership and analysis work enabled measurements in previously unexplored kinematic regions, providing key insights into the behavior of quarks and gluons under the framework of quantum chromodynamics (QCD). The data from HERA fundamentally shaped theoretical models of strong interactions and directly informed experimental strategies at the Large Hadron Collider (LHC), contributing to discoveries such as the Higgs boson and ongoing searches for physics beyond the Standard Model.

Shaw Prize in Astronomy

IOften called the "Nobel of the East," the Shaw Prize in Astronomy honors astronomers whose discoveries have profoundly advanced our understanding of the cosmos. It is awarded for exceptional contributions to observational or theoretical astronomy, from the discovery of new celestial phenomena to major technological developments in space science. In 2024, Shrinivas R. Kulkarni was recognized for his transformative contributions to time-domain astronomy, particularly his pioneering discoveries involving millisecond pulsars, gamma-ray bursts, supernovae, and other transient celestial phenomena.

A professor of astronomy and planetary science at the California Institute of Technology, Kulkarni has long been at the forefront of identifying and understanding some of the most energetic and short-lived events in the universe. His early work on millisecond pulsars and gamma-ray bursts helped establish the observational foundations for compact object astrophysics and the mechanisms behind stellar explosions.

Kulkarni's vision and leadership were instrumental in launching two groundbreaking sky surveys—the Palomar Transient Factory (PTF) and its successor, the Zwicky Transient Facility (ZTF). These projects, under his direction, introduced highly automated

and rapid-scan capabilities to optical astronomy, enabling the discovery and characterization of thousands of transient events, from new types of supernovae to mysterious fast blue optical transients. By dramatically expanding our ability to monitor the dynamic sky, Kulkarni's work has redefined how astronomers explore the cosmos in real time and laid the foundation for the next generation of time-domain surveys, including preparations for the Vera C. Rubin Observatory

Shrinivas R Kulkarni

Muslim Contributions in the Field of Classical Physics

Islam has shaped the course of human civilization in more ways than we often realize. During the Islamic Golden Age—roughly spanning the 8th to 14th centuries—scholars across the Muslim world made groundbreaking advances in science, medicine, mathematics, astronomy, and physics. Far from being passive inheritors of Greek knowledge, Muslim scientists preserved, expanded upon, and innovated in ways that profoundly influenced the trajectory of global science.

This intellectual flourishing, which stretched from the bustling cities of Baghdad and Damascus to the libraries of Cordoba and the observatories of Samarkand, was driven by a deep cultural and religious appreciation for knowledge (‘ilm). Scholars worked under the patronage of caliphs and rulers who valued inquiry, rationalism, and empirical observation—long before these became pillars of the European Enlightenment.

In the realm of classical physics, Muslim scientists laid foundational principles that would eventually inform and inspire later thinkers such as Galileo, Newton, and Kepler. These pioneers explored motion, optics, gravity, and the mechanics of the universe with remarkable insight and precision.

In this article, we will highlight five of the most influential Muslim scientists in the field of classical physics. Ibn Sina (Avicenna) advanced early theories of motion and inertia. Ibn al-Haytham (Alhazen) revolutionized optics and experimental methods. Al-Biruni made lasting contributions to mechanics and gravitation. Al-Khazini explored the physics of weight and balance. And Nasir al-Din al-Tusi developed astronomical models that would later influence Copernicus.

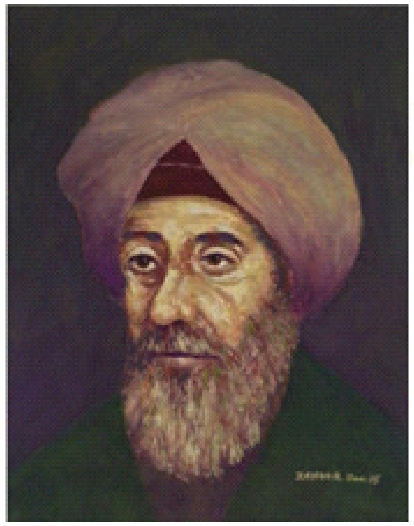
Ibn Sina (Avicenna): A Pioneer of Motion and Mechanics

Abū ʿAlī al-Ḥusayn ibn ʿAbd Allāh ibn Sīnā, known in the West as Avicenna, was a polymath who made enduring contributions to medicine, philosophy, logic, astronomy—and importantly, physics.

Ibn Sina was among the first to question Aristotle's classical theory of motion, which claimed that a continuous force was needed to keep an object in motion. Ibn Sina proposed a radically new concept called mayl (inclination), suggesting that when an object is set in motion, it acquires an internal tendency to keep moving. This motion only ceases when an external force—like air resistance or friction—intervenes. Sound familiar? It should—it's an early precursor to Newton's First Law of Motion (inertia), written centuries later.

He also distinguished between speed and force, observing that force initiates motion but isn't equivalent to it. His assertion that heavier objects don't always fall faster directly contradicted Aristotle. Ibn Sina's approach moved physics away from abstract philosophy toward a more empirical and logical science. His critiques of Aristotelian thought profoundly influenced medieval European scholars such as Thomas Aquinas and Roger Bacon, thanks to Latin translations of his work in the 12th century.

Ibn Sina



Ibn al-Haytham

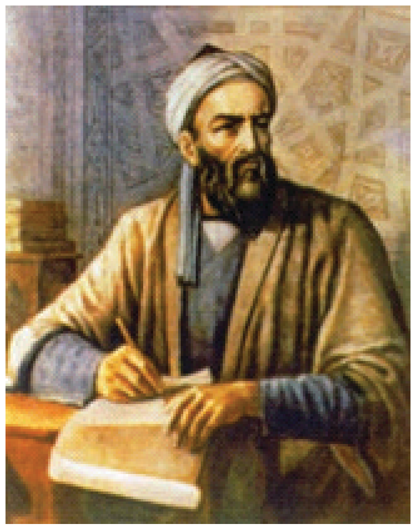
Ibn al-Haytham (Alhazen): The Father of Optics and Experimental Science

Abu Ali al-Hasan ibn al-Hasan ibn al-Haytham, known in the West as Alhazen, was one of the most brilliant physicists of the Islamic Golden Age. Born in Basra in the 10th century and later active in Cairo, he is widely regarded as the “Father of Optics,” though his contributions extend well beyond the study of light. His most influential work, Kitāb al-Manāẓir (The Book of Optics), fundamentally challenged Greek theories by Euclid and Ptolemy, who believed vision occurred because the eyes emitted rays. Ibn al-Haytham correctly argued that vision happens when light reflects off objects and enters the eye in straight lines—a transformative idea supported by careful geometric analysis and experimentation.

In his optical research, he explored reflection, refraction, and visual perception with astonishing accuracy. He explained how rainbows form, investigated the behavior of magnifying lenses, and described the workings of the pinhole camera (camera obscura) centuries before its adoption in Europe. His insights anticipated much of the later work in geometric optics and laid critical groundwork for the development of instruments like telescopes and microscopes.

Beyond optics, Ibn al-Haytham also contributed to hydrostatics and the understanding of fluid pressure. But perhaps his most enduring legacy is his insistence on empirical observation and systematic experimentation. He rejected blind reliance on ancient authorities and emphasized testing hypotheses through controlled, repeatable experiments—a radical approach at the time. His method marked a major shift from philosophical speculation to scientific inquiry and helped establish the foundations of what we now call the scientific method.

Al-Biruni: Measuring the Earth and Reimagining Gravity



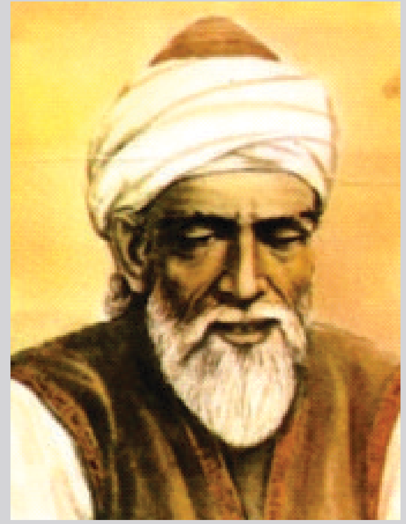
Al-Biruni

No account of Muslim contributions to classical physics would be complete without Abu Rayhan al-Biruni, a polymath whose intellect was centuries ahead of his time. Al-Biruni was one of the first to propose that the Earth rotates on its axis—challenging the dominant geocentric views of his era. Even more remarkably, he proposed that gravity is a mutual force of attraction pulling objects toward the Earth’s center. Though he lacked Newton’s mathematical formulation, the core idea of gravitational attraction marks a powerful conceptual leap toward modern physics.

One of his most impressive feats was calculating the Earth's radius with remarkable precision. Using trigonometric methods and observations from a mountain in present-day Pakistan (Pind Dadan Khan), he estimated the Earth's circumference at 39,960 km—astonishingly close to the modern value of 40,075 km. He also accurately measured the angles of solar and lunar eclipses and estimated the distances between the Earth, Moon, and Sun with methods that showcased his deep understanding of geometry and celestial motion.

What sets Al-Biruni apart is not just his scientific accuracy, but the rigor of his method. He combined mathematical theory with careful observation, often criticizing others for speculation without evidence. His works, such as Al-Qanun al-Mas’udi, a vast encyclopedia of astronomy and physics, reveal a scientist committed to empirical reasoning centuries before it became standard practice. In both spirit and substance, Al-Biruni’s work foreshadowed the scientific revolution and earned him a place among the greatest minds in the history of science..

Al-Khazini: Weighing the Universe



Al-Khazini

Abu’l-Fath Abd al-Rahman Al-Khazini, often remembered as “The Physicist Who Weighed the Universe,” lived in the 12th-century city of Merv, located in present-day Turkmenistan. Remarkably, he began life as a Greek slave but rose to become one of the most brilliant scientific minds under the patronage of the Seljuk rulers. His work exemplifies the intellectual openness and meritocracy that characterized much of the Islamic Golden Age.

Al-Khazini made groundbreaking contributions to hydrostatics and fluid mechanics, fields that were still in their infancy at the time. He designed and built highly accurate hydrostatic balances capable of measuring the density and buoyancy of various materials with unprecedented precision. His methods allowed for more exact comparisons between the weights of substances in air and water, refining principles that dated back to Archimedes. These instruments and techniques were so advanced that they remained in use, with little modification, for centuries.

Perhaps even more visionary was his understanding of gravity. Al-Khazini proposed that gravitational force is not uniform but varies based on the substance and its distance from the Earth's center—an insight that predates Newtonian gravitation by over 500 years. He even attempted to quantify gravitational pull, suggesting it could be measured mathematically rather than discussed purely in philosophical terms. In doing so, Al-Khazini helped shift the study of physics from abstract speculation to empirical and mathematical analysis, a hallmark of modern science. His pioneering approach to physical measurement and experimentation would echo in the scientific methods adopted in Europe centuries later.

Nasir al-Din al-Tusi

Nasir al-Din al-Tusi: The Astronomer Who Inspired Copernicus

Muhammad ibn Muhammad ibn al-Hasan al-Tusi, born in Persia (modern-day Iran), was a master astronomer and mathematician whose work reshaped the cosmos—literally.

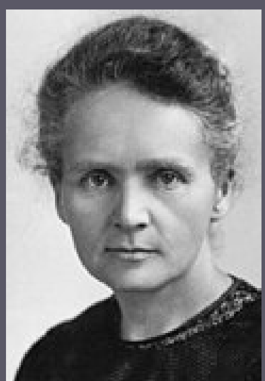
He is best known for devising the Tusi Couple, a mathematical model that produced linear motion from the combination of two circular motions. This innovation corrected flaws in Ptolemy’s planetary model, specifically by eliminating the problematic "equant"—a point that caused planetary motion to violate Aristotle’s principles.

Centuries later, Copernicus used a similar model in his heliocentric theory, suggesting that Tusi’s work directly influenced the Copernican Revolution. Al-Tusi also founded the Maragha Observatory in 1259, which became the most advanced astronomical center of its time. There, he worked with scholars of multiple faiths—Muslim, Christian, and Chinese—and produced the Zij-i Ilkhani, a comprehensive set of astronomical tables that greatly improved the accuracy of planetary data.

The contributions of Muslim scholars to classical physics are prefound, far-reaching, and often underappreciated. From foundational ideas about motion, optics, and gravity to major advances in observational astronomy, these thinkers laid the groundwork for what would eventually become modern science. They did not merely preserve ancient knowledge—they questioned, refined, and expanded it, creating a legacy that continues to inspire scientists around the world.

Breaking the Barrier: Women Nobel Laureates in Physics

Marie Curie



Marie Curie

Maria Skłodowska was born on November 7, 1867, in Warsaw, Poland (in the Russian Empire). She grew up in a family of teachers who valued education. Her early years were marked by financial hardship and the loss of her mother to tuberculosis when she was just 10. Because women were barred from universities in Poland, she worked as a governess to save money and eventually moved to Paris in 1891 to study at the Sorbonne , a University in Paris. There, she earned degrees in physics (1893) and mathematics (1894).

Marie Curie married Pierre Curie, a French physicist, in 1895 and together they began researching radioactiovity, a term coined by Marie herself. They conducted painstaking research under difficult conditions, working in a poorly equipped lab while raising their two daughters, Irène and Ève. Working with Pitchblende (Uranium-rich ore), the curies discovered two new radioactive elements in 1898; Polonium, named after her homeland Poland, and Radium. Her work proved that radioactivity was an atomic property, challenging the then-held belief that atoms were indivisible and immutable. Marie Curie persisted in studying the characteristics of radioactive elements. By 1910, she had isolated radium in its pure metallic form, definitively confirming its status as a distinct element. She meticulously recorded the behavior of radioactive substances and their chemical compounds. These discoveries proved invaluable, as radioactive materials began serving as impotant radiation sources for scientific research and medical applications, particularly in tumor treatment.

The Curies were awarded the Nobel Prize in Physics in 1903 for "Extraordinary services they have rendered by their joint research on the radiation phenomena discovered by Professor Henri Becquerel", with the other half shared by Antoine Henri Becquerel. Marie was widowed in 1906, but continued to work and went on to become the first person ever to be awarded two Nobel Prizes. Facing the unknown health risks, Marie Curie died from aplastic anemia on July 4, 1934.

Maria Goeppert Mayer

Maria Goeppert Mayer

Maria Goeppert Mayer's journey to becoming only the second woman ever to win the Nobel Prize in Physics was marked by relentless determination in the face of systemic sexism. Born on June 28, 1906, in Germany, she grew up in an intellectual family that encouraged her scientific curiosity which was a rarity for girls at the time. While studying Mathematics in the University of Göttingen, she was drawn to Physics and chose to pursue a PhD in it. Her doctoral thesis presented in 1930 put forward the theory of possible two-photon absorption by atoms. After earning her PhD, she faced immediate barriers: no university would hire her as a professor because she was a woman.

For over 15 years, Mayer worked unpaid or in low-status positions while making critical contributions to physics. When she moved to the U.S. with her husband, physicist Joseph Mayer, universities like Johns Hopkins and Columbia only allowed her to work voluntarily or as an assistant, despite her expertise. Even after developing her revolutionary nuclear shell model, many male physicists initially dismissed her ideas. It took years for her theory to gain acceptance, partly because few took female scientists seriously.

Finally, in 1963, she won the 1963 Nobel Prize in Physics (shared with J. Hans D. Jensen and Eugene Wigner) for her groundbreaking work on the nuclear shell model, which explained why certain numbers of protons or neutrons (called "magic numbers") make atomic nuclei exceptionally stable. Building on earlier research, Mayer proposed that nucleons (protons and neutrons) move in orbits within the nucleus, forming energy "shells" similar to electrons in atoms. Her theory resolved long-standing puzzles about nuclear behavior and became fundamental to understanding isotopes, neutron stars, and radioactive decay. Notably, Mayer was only the second woman ever to win the Physics Nobel, 60 years after Marie Curie, yet she was still denied a full professorship until later in her career. Her story is one of brilliance overlooked, perseverance against exclusion, and ultimate triumph in reshaping nuclear physics.

Donna Strickland

Donna Strickland

Born on May 27, 1959, in Guelph, Ontario, Canada, Donna Strickland earned her Bachelor of Engineering in Engineering Physics from McMaster University in 1981. She completed her Ph.D. in 1989 at the University of Rochester where she conducted her doctoral research at the associated Laboratory for Laser Energetics, supervised by Gérard Mourou.

Donna Strickland was awarded the Nobel Prize for her co-invention of chirped pulse amplification (CPA) alongside Gérard Mourou, a revolutionary laser technique that generates ultra-short, high-intensity pulses that could make extremely precise cuts without destroying the amplifying material. By stretching, amplifying, and then compressing laser pulses, CPA enabled unprecedented precision in applications like laser eye surgery, micromachining, and particle acceleration. Strickland's breakthrough, developed during her PhD in the 1980s, transformed laser physics.

Yet, despite her pivotal role in CPA, Strickland's career progressed slowly in a system that underestimated women's contributions. For decades, she remained an associate professor at the University of Waterloo, overlooked for promotions while male peers advanced. Even as CPA became foundational in laser applications, few knew her name—until 2018, when she was awarded the Nobel Prize in Physics, sharing the honor with Mourou.

The win made her the third female physics laureate in history, a shocking statistic that highlighted the field's entrenched gender gap. In interviews, Strickland admitted she hadn't even realized how few women had won before her—proof of how normalized the exclusion of women had become. Currently, Strickland is a professor in the Department of Physics and Astronomy at the University of Waterloo in Ontario, Canada. She leads the Ultrafast Laser Group, focusing on the development of high-intensity laser systems for nonlinear optics investigations.Today, she advocates for more visibility for female scientists, proving that persistence and excellence can break even the toughest barriers.

Andrea M. Ghez

Born on June 16, 1965, in New York City, USA, Andrea Mia Ghez has become one of the most influential astrophysicists of our time. From a young age, Ghez was captivated by the cosmos. Inspired by the Apollo Moon landings, she dreamed of becoming the first female astronaut—a vision her mother nurtured by gifting her a telescope, sparking what would become a lifelong passion for space.

Her academic path was shaped by her family's move to Chicago in 1969, where her father took a faculty position at the University of Chicago. This allowed her to attend the university's Laboratory School, an intellectually stimulating environment that supported her early scientific interests. Ghez pursued her undergraduate degree in Physics at MIT, graduating in 1987, and went on to earn her Ph.D. in Physics from Caltech in 1992, where she began focusing on astronomical imaging techniques and star formation.

Andrea M. Ghez

Ghez rose to international prominence for her groundbreaking study of Sagittarius A* (Sgr A*), the supermassive black hole at the center of the Milky Way galaxy. For over two decades, she used cutting-edge adaptive optics technology at the W. M. Keck Observatory in Hawaii to precisely track the motion of stars orbiting an invisible point at the galactic core. Her meticulous observations revealed that the stars were moving at incredible speeds—evidence that could only be explained by the gravitational pull of a massive, compact object: a black hole with a mass of about 4.1 million times that of the Sun.

This research provided the most convincing evidence to date for the existence of a supermassive black hole and confirmed predictions made by Einstein's theory of general relativity under conditions of extreme gravity. In 2020, Ghez was awarded the Nobel Prize in Physics, shared with Roger Penrose and Reinhard Genzel. She became only the fourth woman in history to receive the Nobel in Physics—an achievement that not only highlights her scientific legacy but also marks a significant step forward for women in STEM.

Currently, Ghez serves as a professor in the Department of Physics and Astronomy at the University of California, Los Angeles (UCLA), where she holds the Lauren B. Leichtman & Arthur E. Levine Chair in Astrophysics. She is the leader of the UCLA Galactic Center Group, a research team that focuses on high-resolution imaging and the dynamic behavior of stars in the vicinity of Sagittarius A*. Their work continues to push the boundaries of our understanding of gravity, galaxy formation, and the role black holes play in the evolution of the universe.

Beyond her scientific accomplishments, Andrea Ghez is also a passionate advocate for education and gender equity in science. She has spoken extensively about the importance of mentorship, diversity, and encouraging young women to pursue careers in physics and astronomy. By breaking barriers in a traditionally male-dominated field, Ghez not only revealed the hidden forces at the center of our galaxy but also illuminated a path for future generations of scientists.

> "One of the things that's so wonderful about science is that it's driven by curiosity."
>
> ~Andrea Ghez

> "In a field long defined by silence and shadows, these women lit the way—not only by advancing the frontiers of physics, but by proving that brilliance knows no gender."
>
> ~Marie Curie

Anne L'Huillier

Anne L'Huillier

Anne L'Huillier is a French-Swedish physicist whose pioneering work in attosecond physics has reshaped our understanding of ultrafast phenomena in atoms and molecules. Born on August 16, 1958, in Paris, France, she grew up in a family that valued education and scientific inquir. L'Huillier pursued her higher education at the École Normale Supérieure in Fontenay-aux-Roses, earning a bachelor's degree in mathematics, followed by a master's degree in theoretical physics and mathematics at the Université Pierre et Marie Curie (Sorbonne University). She then completed her Ph.D. at the Commissariat à l'Énergie Atomique (CEA) in Saclay in 1986, focusing on the interaction of intense laser fields with atoms, specifically multiphoton and multielectron ionization processes.

In 1987, Anne L'Huillier first observed that gases like argon would react to a laser by becoming excited and emitting additional radiation or overtones, at various multiples of the frequency of laser. This phenomenon, known as high harmonic generation (HHG), became the cornerstone of her later research. Over the following years, L'Huillier and her collaborators developed a deep quantum mechanical understanding of HHG, leading to the realization that this process could produce bursts of light lasting only attoseconds (10^{-18} seconds). By 2003, her group had achieved the generation of laser pulses as short as 170 attoseconds, setting a world record. These attosecond pulses allowed scientists, for the first time, to observe electron motion in real-time, opening the door to a new field often referred to as attochemistry — the study of chemical and physical changes occurring on the timescale of electron movement.For her pivotal contributions, Anne L'Huillier was awarded the Nobel Prize in Physics in 2023, an honor she shared with Pierre Agostini and Ferenc Krausz. Their combined work was cited "for experimental methods that generate attosecond pulses of light for the study of electron dynamics in matter." With this, L'Huillier became the fifth woman in history to receive a Nobel Prize in Physics, joining the ranks of legends like Marie Curie and Maria Goeppert-Mayer. Her achievements have not only advanced basic science but have also laid the foundation for practical applications in imaging, electronics, and quantum technology.

Since 1997, Anne L'Huillier has been a professor of atomic physics at Lund University in Sweden, where she leads a vibrant research group focused on attosecond science. She also plays a significant leadership role in the Wallenberg Centre for Quantum Technology (WACQT), a major Swedish initiative to develop cutting-edge quantum technologies. In addition to the Nobel Prize, her career has been recognized with numerous other prestigious honors, including the UNESCO L'Oréal Award for Women in Science, the Wolf Prize in Physics, and the BBVA Foundation Frontiers of Knowledge Award. Her election to institutions like the Royal Swedish Academy of Sciences and the French Académie des Sciences further reflects her status as one of the most influential physicists of our time.

In recent years, a remarkable number of distinguished women physicists have received some of the world's most prestigious scientific honors, highlighting their profound contributions to both fundamental research and applied science. These accolades from national medals and international fellowships to specialized disciplinary awards reflect the exceptional caliber of their work and the growing recognition of women as leaders in physics. Their pioneering research spans diverse fields such as quantum optics, astrophysics, condensed matter physics, and mathematical physics, demonstrating the extraordinary breadth and depth of their impact. Beyond their scientific achievements, many of these trailblazers are celebrated for their dedication to public engagement, mentoring, and advocacy for equity and inclusion in science. By breaking barriers and fostering opportunities for underrepresented groups, they are not only advancing the frontiers of knowledge but also transforming the culture of the scientific community. This section honors these inspiring women whose groundbreaking work and leadership continue to shape the global landscape of physics and inspire the next generation of scientists.

Women Who Lead: Global Recognition in Physics

Ingrid Daubechies

In 2023, Ingrid Daubechies made history as the first woman to win the prestigious Wolf Prize in Mathematics, and in 2025 she was awarded the National Medal of Science, the highest scientific honor in the United States. These accolades recognize her groundbreaking contributions to wavelet theory—a powerful mathematical tool that has revolutionized how data is processed and interpreted. Daubechies' work underpins many technologies we use today, from MRI scans to image compression, enabling clearer images and faster communications. As a James B. Duke Distinguished Professor Emerita at Duke University, she is also a passionate mentor, dedicated to encouraging women in STEM. Her career reflects a blend of deep theoretical insight and practical innovation that has broken barriers in a traditionally male-dominated field.

Nicola Spaldin

Nicola Spaldin was honored with the Gothenburg Lise Meitner Award in 2023 for her pioneering research on multiferroic materials—compounds that uniquely combine magnetic and electric properties. This work has opened new frontiers in materials science, leading to potential advances in faster memory devices and smarter sensors. Spaldin's research bridges theory and real-world applications, making a significant impact on next-generation electronics. Beyond her scientific achievements, she is a committed advocate for diversity and inclusion, mentoring young scientists and fostering a collaborative and equitable research environment.

Jocelyn Bell Burnell

In 2023, Jocelyn Bell Burnell received the Royal Irish Academy's Cunningham Medal in recognition of her landmark discovery of radio pulsars in 1967. This breakthrough revealed rapidly spinning neutron stars and revolutionized our understanding of stellar evolution and extreme cosmic phenomena. Bell Burnell's influence extends well beyond her discovery. A passionate advocate for equity in science, she has used her Nobel Prize funds to support scholarships for women and minorities. Her dedication to mentoring and inclusion has inspired generations of scientists and helped make the scientific community more welcoming and diverse.

Jelena Vučković

Jelena Vučković was elected to the National Academy of Sciences in 2023 in recognition of her pioneering contributions to quantum photonics. Her groundbreaking research on photonic crystal devices and quantum light sources is pushing the boundaries of how light can be controlled and manipulated at the nanoscale. This work is paving the way for major advances in quantum computing, ultra-secure optical communication, and integrated photonic circuits, technologies that could transform everything from information security to computing power. Vučković's unique ability to bridge theoretical models with experimental realizations has established her as a leading figure in the rapidly evolving field of quantum optics. Beyond her scientific achievements, she is a passionate mentor and advocate for diversity in STEM, actively working to create a more inclusive environment for emerging scientists and fostering collaboration across disciplines.

Sumathi Rao

Sumathi Rao was elected a Fellow of the American Physical Society in 2022 for her influential theoretical research on electronic transport in low-dimensional and strongly correlated systems, such as quantum wires and topological phases of matter. Her deep insights into the behavior of electrons confined to ultra-thin materials are foundational for the development of next-generation nanoelectronic and quantum devices, which promise to revolutionize computing and electronics. Rao's work has helped uncover new physics in condensed matter systems, highlighting the rich and complex interactions that emerge at reduced dimensions. In addition to her scientific excellence, Rao is a dedicated mentor who has tirelessly championed gender equity in physics. She actively works to break down barriers for women and underrepresented groups in the field, making significant contributions to creating a more supportive and diverse scientific community. Her commitment to both research and social progress has made her a respected leader among peers and students alike.

Maggie Aderin-Pocock

In 2020, Maggie Aderin-Pocock was awarded the William Thomson, Lord Kelvin Medal by the Institute of Physics, recognizing her exceptional contributions to public engagement with science. As a space scientist with a charismatic presence, she has brought the wonders of the universe into living rooms and classrooms worldwide through television, public talks, and educational outreach programs. Her passion for making complex scientific concepts accessible and exciting has inspired countless young people, especially those from underrepresented backgrounds, to pursue careers in STEM fields. Aderin-Pocock's personal journey overcoming dyslexia adds a powerful dimension to her advocacy for diversity and inclusion in science, demonstrating resilience and determination in the face of challenges. Through her work, she continues to break down barriers and stereotypes, encouraging a new generation to dream big and explore the mysteries of the cosmos.

> "Do not wait for leaders. Do it alone, person to person."
> ~Mother Teresa

A Century of Quantum Mysteries and the Road Ahead

About the Author:

FAISAL MEHMOOD is a young quantum scientist and researcher at the Pakistan Institute of Engineering and Applied Sciences (PIEAS), specializing in quantum entanglement in neutrino oscillations, open quantum systems, and their connection to quantum information and computation. His research focuses on advancing our understanding of fundamental quantum phenomena and exploring their applications in particle physics and emerging quantum technologies. In addition to research, he is passionate about mentoring young scientists and fostering collaboration across disciplines to promote scientific innovation, creativity, and knowledge sharing. You can reach the author at faisalmehmood@pieas.edu.pk

"As quantum theory celebrates its 100th birthday, spectacular successes are mixed with persistent puzzles."

Imagine a world where reality defies intuition: Particles act like waves, cats are both alive and dead, and the act of observing changes what you see. Welcome to quantum mechanics, the science that has reshaped our understanding of the universe and powered technologies from smartphones to MRI scanners. As we celebrate 2025—the International Year of Quantum Science and Technology—we look back at 100 years of quantum thinking. It all began in 1925, when a group of brilliant young minds dared to question the physics of their time. Since then, quantum mechanics has opened new windows into the universe, powering innovations from lasers and GPS to medical imaging and quantum computers. But quantum physics is more than just equations and experiments—it's a story of bold ideas, fierce debates, and mysteries that still puzzle scientists today. What makes quantum so strange yet so powerful? How did it change the course of science? And where is it taking us next? Join me, to explore a century of quantum breakthroughs—and the thrilling future that lies ahead.

Birth of Quantum Ideas

By the end of the 19th century, the science of physics was built on three strong foundations: mechanics, electrodynamics, and thermodynamics. These three pillars seemed to cover nearly all aspects of the physical world. From the motion of planets to the behavior of steam engines, everything appeared to follow well-defined laws. These principles were so successful in explaining the natural world that many scientists believed physics was essentially complete. The world, it seemed, was a well-oiled machine — predictable, deterministic, and fully knowable. In fact, the renowned physicist Lord Kelvin famously declared in 1900 during a lecture to the British Association for the Advancement of Science: *"There is nothing new to be discovered in physics now. All that remains is more and more precise measurement." But* there were some experimental results unexplained by the existing theories like stability of atoms and the strange behavior of heat radiation from objects—what we now call blackbody radiation. Classical theories couldn't explain why objects emitted different colors of light at different temperatures. The second puzzle came from the failure of Michelson–Morley experiment to detect the mysterious *"aether"* that light was supposed to travel through. Kelvin said no need to worry, these are the "*minor clouds,"* would soon be resolved within the existing framework. But those small clouds didn't fade—they grew into storms. Out of these storm, two groundbreaking theories began to take shape — quantum mechanics and the theory of relativity. These weren't just small corrections; they completely changed how we understand nature, challenging the very foundations on which classical physics had stood for centuries.

Classical physics predicted that as an object gets hotter, it should emit more and more energy at shorter wavelengths, especially in the ultraviolet range. But experiments showed something different: the energy peaked at a certain wavelength and then dropped off, forming a curve that classical theories couldn't explain. This mismatch between theory and experiment known as the "ultraviolet catastrophe." To solve this, German physicist Max Planck made a bold and unusual move. In 1900, he introduced a mathematical trick — he assumed that energy could only be absorbed or emitted in tiny, fixed amounts called "quanta," instead of flowing smoothly like a continuous stream. This simple idea allowed his formula to match the experimental graph perfectly. At the time, Planck didn't think this had any deep meaning; he believed it was just a clever tool to fit the data. But this trick turned out to be much more than that. It was the seed of an entirely new theory of nature. While Planck had introduced the idea of energy being released in tiny packets, he still believed this was just a clever mathematical trick to make his formula match the experimental curve. But in 1905, a young physicist named Albert Einstein took this idea much more seriously. He suggested that light itself might be made up of these tiny energy packets, which we now call photons. In his paper on the photoelectric effect, Einstein didn't call them "photons" — he used the term *light quanta*. The word *photon* was introduced later in 1926 by chemist Gilbert N. Lewis. This bold idea helped explain a puzzling experiment known as the photoelectric effect. In this experiment, scientists observed that shining light on a metal surface could knock out electrons from it — but only if the light had a certain minimum frequency, no matter how bright it was. Classical physics couldn't explain this at all. According to the old view, increasing the brightness (which means more energy) should knock out more electrons, but it didn't. Einstein explained that only light with enough energy per photon could do the job, and this energy depended on the light's frequency, not its brightness. His explanation not only solved the mystery, but also confirmed that energy was truly quantized — a core idea of what would soon become quantum mechanics.

In the early 1900s, the existence of atoms was still a matter of debate. Although the electron had been discovered by J.J. Thomson in 1897, many scientists were not convinced that atoms were real physical entities. In 1905, Albert Einstein published a remarkable paper explaining the random motion of tiny particles suspended in a fluid—what we now call Brownian motion. He showed that this behavior could only be understood if atoms and molecules actually existed. By analyzing the motion and comparing it to statistical mechanics, Einstein was able to estimate Avogadro's number, giving strong theoretical proof for the atomic nature of matter. It was one of the first convincing pieces of evidence that atoms are real. A few years later, in 1909, Ernest Rutherford and his team at the University of Manchester carried out a famous experiment. They bombarded a thin gold foil with alpha particles and observed that some of them bounced back. This surprising result led Rutherford to propose that most of the atom's mass and positive charge is concentrated in a small, dense nucleus at the center. This nuclear model of the atom replaced the older "plum pudding" model and gave a new direction to atomic theory. Around this time, a young Danish physicist Niels Bohr became interested in atomic structure. He traveled to England and joined Rutherford's group in Manchester to learn more about the atom. Bohr admired Rutherford's experimental work, but he also saw a problem: classical physics could not explain why electrons orbiting the nucleus didn't lose energy and spiral inward. To resolve this, Bohr proposed a bold new model in 1913 while working as a postdoctoral researcher under Rutherford. He introduced the idea that electrons could only occupy certain allowed orbits without radiating energy, and that they could jump between these orbits by absorbing or emitting discrete amounts of energy. This model explained the spectral lines of hydrogen with great accuracy but failed to explain multi-electron atoms and didn't account for fine structure or quantum spin. Back in Copenhagen, Bohr got a letter from Rutherford telling him he had to publish his results. Bohr wrote back that nobody would believe him unless he could explain the spectra of all the atoms. Rutherford replied, in effect: Bohr, you explain hydrogen and you explain helium and everyone will believe all the rest. Indeed, the Bohr model was a major success—at least for hydrogen. It marked the first time a theoretical model based on quantum ideas matched experimental data so precisely. Unlike Newton's laws or Maxwell's equations, Bohr's model was not a full theory but rather a set of postulates designed to explain the hydrogen atom. It is interesting to observe how the understanding of subatomic particles evolved through a chain of mentorship: Thomson discovered the electron, his student Rutherford uncovered the nucleus and the proton, and Rutherford's student James Chadwick identified the neutron in 1932, while working in Rutherford's laboratory. Around the same time, Niels Bohr, who had also worked with Rutherford, contributed the first successful quantum model of the atom, explaining atomic stability and spectral lines.

Now, the atom was no longer a simple solar system of electrons orbiting the nucleus—it was a strange, rule-bound world governed by probability and energy levels. But something wasn't adding up. Physicists knew that electrons arranged themselves in "shells" around the nucleus, and each shell could only hold a specific number of electrons. But no one knew why. Why did hydrogen, with just one electron, behave so differently from helium, with two? Why did atoms build up the periodic table in such a systematic way? What secret rule was guiding the electrons? This puzzle grew more frustrating as atomic spectra became better measured. Scientists could see clear patterns in the way atoms absorbed and emitted light, yet the theory couldn't explain why some electron states were allowed and others were forbidden. Then, in 1925, Wolfgang Pauli, a young Austrian physicist, offered a revolutionary answer: no two electrons in an atom can share the same set of quantum numbers—in other words, no two electrons can occupy the exact same quantum state. This became known as the Pauli Exclusion Principle. With this simple but powerful rule, Pauli solved the mystery of electron arrangements in atoms. Suddenly, the structure of the periodic table made sense. The reason electrons stacked in certain ways wasn't chaos—it was quantum law. Each electron needed its own unique quantum identity. But the implications went far beyond chemistry. Pauli's principle became the foundation for our understanding of fermions—a class of particles (like electrons, protons, and neutrons) that build up all matter. It even explains why matter has rigidity, why atoms don't collapse into each other, and why stars like white dwarfs don't implode under their own gravity. This principle wasn't just a technical rule—it was a hidden law of nature, one that dictated how the universe builds complexity, from the smallest atoms to the largest galaxies. In recognition of his fundamental contribution, Pauli was awarded the Nobel Prize in Physics in 1945. In fact, decades later, Indian-American Physicist Chandrasekhar used this principle to describe how stars evolve, earning him a Nobel Prize in 1983.

In the early 1920s, Louis de Broglie, a young French physicist from a noble family, switched from studying history to physics during World War I. While pursuing his PhD at the University of Paris, he found himself captivated by a puzzling symmetry in nature: if light, once thought to be a wave, could also behave like a particle—as Einstein had shown—then why couldn't particles, like electrons, also behave like waves? With this daring question, de Broglie introduced a radical idea in his 1924 doctoral thesis: every particle of matter has an associated wavelength linking the tiny quantum world to the language of waves. His supervisor, Paul Langevin, a respected physicist, was intrigued but unsure. When de Broglie submitted his thesis, the examination committee was confused and skeptical—no one had ever heard of such an idea. The story goes that they hesitated to grant him the degree and sought the opinion of none other than Albert Einstein. Upon reading de Broglie's thesis, Einstein immediately recognized its depth and called it a "step of genius." With Einstein's endorsement, the committee awarded de Broglie his doctorate. But what did it mean for particles to be both waves and particles? This question, still debated today, marked the birth of modern quantum mechanics. The Nobel Laureate Julian Schwinger said, *"Quantum mechanics is a totally new way of looking at the world, and it's the only way that works at the atomic level*." De Broglie's idea quietly waited for its moment—until Erwin Schrödinger picked it up a couple of years later. Schrödinger was trying to understand atomic structure more deeply and was inspired by de Broglie's notion of wave-like electrons. During a discussion in Zurich, physicist Peter Debye reportedly challenged Schrödinger by asking, *"If electrons are waves, where is the wave equation?"* Motivated by this question, Schrödinger retreated to the Swiss Alps and, over a few weeks in 1926, developed what became the famous Schrödinger wave equation. This equation described how the wavefunction of a quantum particle evolves and could explain the energy levels of hydrogen more accurately than Bohr's model—without assuming any fixed orbits. But what did it all mean? What was the quantity, the "wave function," that Schrödinger's equation described? This central puzzle of quantum mechanics remains a potent and controversial to this day. Max Born, a student of David Hilbert, had the insight that the wavefunction should be interpreted in terms of probabilities, leading to nondeterministic future of the universe. Erwin Schrödinger once said about quantum implications that, *"I don't like it, and I'm sorry I ever had anything to do with it, but it's the only way we've got to understand the atom."* Thus, de Broglie's bold PhD idea laid the foundation for a new way of looking at matter and directly influenced the creation of modern quantum mechanics.

While Schrödinger was developing his wave ideas in the peaceful Alps, another young physicist in Germany was taking a completely different path. In 1925, a brilliant young German physicist named Werner Heisenberg, working under the mentorship of Max Born at the University of Göttingen, devised a bold new way to describe

atoms—without using pictures of orbits or waves. Instead, he focused solely on measurable quantities such as energy levels and transition frequencies, arranging them into mathematical arrays now known as matrices. He only solved harmonic oscillator not hydrogen atom. This method, though abstract and initially difficult to interpret, gave surprisingly accurate results. Born, along with his colleague Pascual Jordan, helped develop this idea into what became known as matrix mechanics—the first fully formed version of quantum mechanics. At first, it seemed unrelated to Schrödinger's wave mechanics, and physicists were divided over which description truly captured nature's behavior. But soon, it was discovered that the two approaches, though mathematically different, were fundamentally equivalent—two sides of the same quantum coin. At just 24 years old, Heisenberg developed matrix mechanics, while Schrödinger, at the age of 40, introduced his famous wave equation. This unique competition between young brilliance and mature experience shaped the very foundations of quantum mechanics.

Just when things were starting to make sense, Werner Heisenberg introduced a bold new idea in 1927 that surprised everyone—the uncertainty principle. It said that we can never know both the exact position and exact momentum of a particle at the same time. If we try to measure one very precisely, the other becomes more uncertain. This wasn't due to bad measurements—it was a built-in feature of nature. This idea completely changed how scientists viewed the microscopic world.

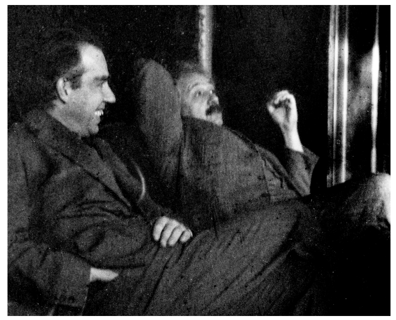


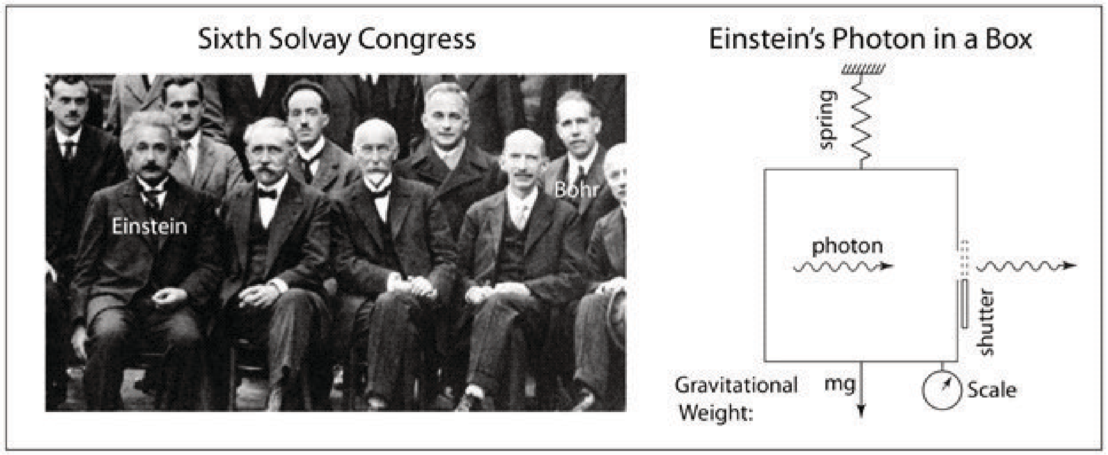
Fig. 1: Niels Bohr (*left*) with Albert Einstein (*right*) at Paul Ehrenfest's home in Leiden (December 1925)

The Copenhagen Interpretation and the Einstein–Bohr Debate

In the 1920s, a revolutionary idea emerged from the city of Copenhagen, Denmark, where physicist Niels Bohr and his colleagues, including Werner Heisenberg, laid the foundation of what became known as the Copenhagen interpretation of quantum mechanics. According to this interpretation, particles like electrons or photons do not have definite properties—such as position or momentum—until they are measured. In other words, reality is not fixed until we observe it. The wavefunction, a key element in quantum theory, describes all the possible outcomes, and when we measure the system, the wavefunction collapses to one result. This strange idea shocked many scientists, especially Albert Einstein, who famously asked, *"Do you really believe the moon exists only when you look at it?"* He rejected the idea that observation could affect reality and believed something deeper must be missing in the theory. But the Copenhagen view insisted that quantum events are fundamentally probabilistic, not deterministic. Despite ongoing philosophical debates, the Copenhagen interpretation became the most widely accepted framework for understanding the quantum world, and it still forms the backbone of much of modern quantum physics.

Fig. 2: The Solvay Conference in October 1927 where the world's famous physicists met to discuss the new quantum theory. Of the 29 participants, 17 were or became Nobel Laureates.

Many physicists accepted it, but Albert Einstein had a hard time agreeing with it. He believed that nature must follow strict rules and that everything could, in principle, be known with enough precision. He famously said, *"God does not play dice with the universe."* In fact, during a heated discussion at the Solvay Conference in Brussels, Einstein tried to challenge Heisenberg's idea by proposing a clever thought experiment to disprove it. In this scenario, Einstein imagined a box filled with light (photons), equipped with a shutter and a clock. He proposed that if one photon escaped the box and the mass of the box was measured before and after, then by energy conservation, one could determine the energy of the photon—and with precise timing, even its time of emission. This would mean knowing both the energy and time with arbitrary accuracy, violating Heisenberg's uncertainty principle. Bohr, though initially shaken, brilliantly countered Einstein the next day. He pointed out that measuring the mass of the box would involve placing it on a scale, which itself would be affected by gravity. According to general relativity, the position of the box in the gravitational field would influence time measurement, preserving the uncertainty principle. This intellectual duel between two giants highlighted a deep philosophical divide: Einstein's insistence on a reality independent of measurement versus Bohr's view that reality is defined by what we can observe and measure.



Einstein's Final Challenge: EPR and the Rise of Bell's Theorem

Even after the Solvay debates, Einstein wasn't satisfied. In 1935, he teamed up with Boris Podolsky and Nathan Rosen to publish a famous paper—now called the EPR paradox. They tried to show that quantum mechanics was incomplete. Their thought experiment described two particles that interact and then move far apart—highlighted quantum's bizarre nature. Could particles really influence each other faster than light? According to quantum theory, measuring one instantly affects the other—even if they're light-years apart. Einstein called this "spooky action at a distance" and argued that something must be hidden—some hidden variables—to explain this strange connection without breaking the rule that nothing travels faster than light. Years later, in the 1960s, physicist John Bell took this argument seriously. He created a testable way to check whether such hidden variables could exist. His idea, known as Bell's inequality, showed that if hidden variables were real, certain mathematical limits should not be violated. But when scientists performed experiments (like those by Alain Aspect in the 1980s), they found that Bell's inequality was violated, just as quantum mechanics predicted. This meant Einstein's idea of hidden variables couldn't explain the results—the spooky action was real. This was a huge moment in science. It showed that the universe is truly connected in mysterious ways. To honor this achievement, Alain Aspect was awarded the Nobel Prize in Physics in 2022, along with John Clauser and Anton Zeilinger, for their groundbreaking experiments with quantum entanglement. This shook the foundations of reality and showed that the universe is even stranger than Einstein imagined. What once seemed like science fiction became scientific fact.

Quantum Choices and the Birth of Multiverse

The idea of parallel universes often called the multiverse, comes from the Many-Worlds Interpretation (MWI), proposed by Hugh Everett III in 1957. He was trying to solve a strange question in quantum mechanics: when we observe something that has many possible outcomes, why do we only see one? Everett's bold idea was that all outcomes actually happen, but in different universes. Think of flipping a coin. While it's in the air, quantum mechanics says it's both heads and tails at the same time—a mix of possibilities. When it lands, we see only one result, maybe heads, and think the other option is gone, same goes with Schrodinger's cat. But Everett said it's not

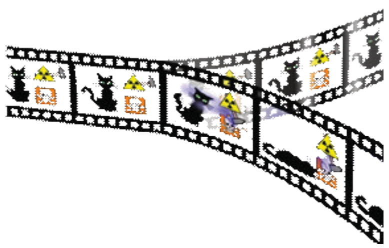


Fig. 3: The quantum-mechanical *Schrödinger's cat paradox* according to the many-worlds interpretation. In this interpretation, every quantum event is a branch point; the cat is both alive and dead, even after the box is opened, but the alive and dead cats are in different branches of the multiverse, both of which are equally real, but do not interact with each other.

gone—it happened in another universe. In one universe, you won the bet and feel happy; in another, you lost and feel sad. Both versions of you exist, just in different realities. This means reality might constantly split, creating countless parallel universes with different versions of events. Some scientists like this idea because it the mysterious collapse of quantum states, but others find it too extreme because we have no direct evidence

for these universes. For now, it remains one of the most fascinating and debated ideas in physics.

When Quantum Becomes Classical: The Role of Decoherence

Schrodinger pointed out that if microscopic objects like atoms could be in strange superpositions, so could macroscopic objects, since they are made of atoms. First of all, if the world actually contains bizarre macro superpositions, then why don't we perceive them? The answer came in 1970 with a seminal paper by Dieter Zeh of the University of Heidelberg, who showed that the Schrodinger equation itself gives rise to a type of censorship. This effect became known as decoherence, because an ideal pristine superposition is said to be coherent. They found that coherent quantum superpositions persist only as long as they remain secret from the rest of the world. Decoherence explains why we do not routinely see quantum superpositions in the world around us. It is not because quantum mechanics intrinsically stops working for objects larger than some magic size. Instead, macroscopic objects such as cats and cards are almost impossible to keep isolated to the extent needed to prevent decoherence. Microscopic objects, in contrast, are more easily isolated from their surroundings so that they retain their quantum secrets and quantum behavior.

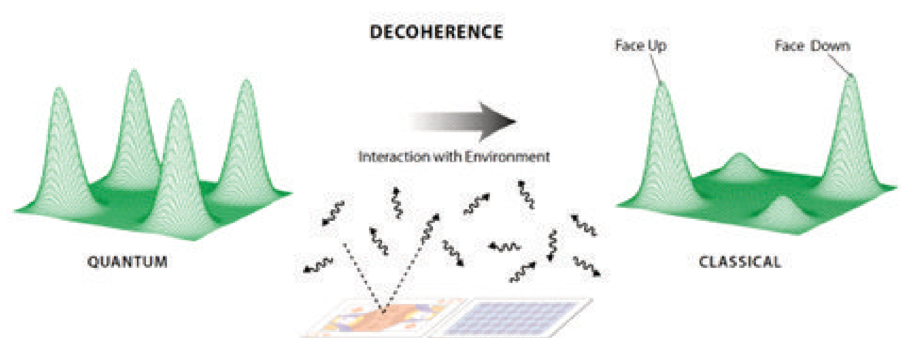


Fig. 4: *Decoherence theory reveals that the tiniest interaction with the environment, such as a single photon or gas molecule bouncing off the fallen card, transforms a coherent density matrix very rapidly into one that, for all practical purposes, represents classical probabilities such as those in a coin toss. The Schrödinger equation controls the entire process.*

Now, what if the time-evolution of the entire Universe is always unitary? Decoherence answered this question as well. If the time-evolution of the entire Universe is always unitary (meaning it always follows Schrödinger's equation without any collapse), then superpositions never actually disappear. Instead, decoherence explains why we *perceive* only one outcome. The calculations showed that classical states could be defined and identified as simply those states that were most robust against decoherence. For example, if we put the card in the state "face up", it would stay "face up" in spite of decoherence in classical states. Everett's idea that physics is unitary that there is no wave function collapse. Even though the wave function technically never collapses in the Everett view, it is generally agreed that decoherence produces an effect that looks like a collapse and smells like a collapse.

If the time evolution of the entire universe is always unitary, it would imply that the universe's evolution is deterministic and reversible, with information perfectly conserved. This means that no information is lost during the universe's expansion or any other process, and the universe's state at any given time could, in principle, be traced back to its initial state. A unitary universe would be potentially time-symmetric system, as it would not inherently possess a preferred direction of time. It would also present challenges to our current understanding of cosmology and the arrow of time.

Quantum Physics and the End of the Deterministic World

Thanks to quantum mechanics, we can now explain almost every mystery of matter and energy. But the price we paid is profound—the future is no longer certain, only a cloud of probabilities. Before the birth of quantum, the universe worked like a giant machine—completely deterministic. According to this classical view, if we knew all the conditions of a system, such as the position and speed of every particle, we could predict exactly what would happen next. This confidence came from the success of Newton's laws, which formed the foundation of classical physics, painting a picture of a predictable, stable, and well-behaved universe. But this certainty began to unravel with the birth of quantum mechanics.

"Quantum mechanics has taught us that reality isn't what it seems. It's not predictable, not fixed, not even fully knowable. But it is powerful, and it is beautiful."

Max Born gave a new interpretation to Schrödinger's wavefunction: instead of describing a physical, spread-out particle, he proposed that it represented the probability of finding the particle at a particular place. This was a radical shift—it meant physics could no longer predict exact outcomes, only the likelihood of different possibilities. Heisenberg's uncertainty principle added to this revolution by showing that certain pairs of properties, like position and momentum, could never be known simultaneously with perfect accuracy. Experiments like the double-slit reinforced the idea that particles don't follow predictable paths but behave more like waves of possibilities. These revelations were deeply unsettling, especially for Einstein, who firmly believed that nature could not be ruled by chance. He suspected something deeper was missing from the theory. Yet despite his doubts, quantum mechanics continued to succeed in experiment after experiment, forcing the scientific community to accept a strange new truth: at its core, the universe is not entirely predictable. Even with all our knowledge, we cannot always explain why something happens or foresee precisely what will happen next—leading many to conclude that quantum mechanics has replaced the classical world's comforting certainty with profound mystery.

Dirac's Unification of Quantum Mechanics and Relativity

While Einstein and Bohr debated the meaning of quantum mechanics, another giant of physics, Paul Dirac, made one of the most profound breakthroughs in theoretical physics. In 1928, he aimed to unite two powerful theories: quantum mechanics and Einstein's special relativity. At that time, Schrödinger's equation could describe slow-moving (non-relativistic) particles like electrons in atoms, but it didn't work for particles moving near the speed of light. Why? Because it didn't include the effects of time and space as described by relativity, and it predicted wrong energy values—sometimes even imaginary energies, which made no physical sense. Dirac wrote a new equation that obeyed both the rules of quantum theory and special relativity. This Dirac Equation not only correctly described fast-moving electrons, but also made a stunning prediction: the existence of antimatter—particles just like electrons but with opposite charge. This was purely theoretical until Carl Anderson discovered the positron (the electron's antiparticle) in 1932 using a cloud chamber. Anderson's discovery provided direct evidence of antimatter and confirmed Dirac's bold theory. As a result, Dirac was awarded the Nobel Prize in Physics in 1933, shared with Erwin Schrödinger. A few years later, in 1936, Carl Anderson himself was honored with the Nobel Prize for his discovery. Dirac's work opened the door to quantum field theory and to our modern understanding of particles and antiparticles, matter and antimatter—revealing the deep symmetries hidden in the universe.

Birth of Quantum Field Theory and Quantum Electrodynamics

After Dirac's groundbreaking equation and the discovery of the positron, physicists began to realize that particles could be created and destroyed — something the earlier versions of quantum mechanics couldn't explain. This led to the development of a more complete theory: Quantum Field Theory (QFT). In QFT, particles are seen as excitations in underlying fields, much like a ripple on the surface of water. For example, an electron is an excitation in the electron field, while a photon (a particle of light) is an excitation in the electromagnetic field. Building on this framework, physicists constructed Quantum Electrodynamics (QED) — the quantum theory of how light and matter interact. QED described how atoms emit and absorb photons through changes in the energy levels of their electrons, and how those interactions follow precise probabilistic rules. However, early attempts at QED ran into serious problems — the equations gave infinite answers for things like energy, which made no physical sense. The rescue came in the 1940s, with the development of a technique called renormalization, which allowed physicists to cancel out the infinities and extract meaningful predictions. Key contributors to this breakthrough were Richard Feynman, Julian Schwinger, and Sin-Itiro Tomonaga. Feynman, in particular, introduced a beautiful and intuitive way to visualize particle interactions through his now-famous Feynman diagrams, which became a standard tool in particle physics. For their pioneering work in QED, Feynman, Schwinger, and Tomonaga were awarded the Nobel Prize in Physics in 1965.

Quantum's Golden Age: Technology Transformed

"The existing scientific concepts cover only a very limited part of reality, and the other part that has not yet been understood is infinite. Quantum mechanics has opened this gate to the infinite."

—Werner Heisenberg

For decades, quantum mechanics remained a theory confined to textbooks and thought experiments. By the 1930s, quantum mechanics was no longer a theoretical curiosity—it was the foundation of modern science. It explained the periodic table, the behavior of stars, and chemical bonds. The mid-20th century witnessed

quantum theory giving birth to transformative technologies. Engineers built lasers and transistors—unaware they were harnessing quantum effects. The transistor, invented in 1947, relied on quantum principles to control electron flow, paving the way for computers and the internet. The first maser (1953) and laser (1960) were early quantum devices, yet few recognized their deeper implications. Lasers, LEDs, and solar cells followed, each a quantum innovation. Medical imaging like MRI scanners harnessed quantum properties of atomic nuclei. How often do you use a device—your phone, a GPS, or a hospital scanner—that owes its existence to quantum mechanics? The answer might surprise you: quantum is everywhere.

The late 20th century marked the second quantum revolution, scientists moved beyond understanding quantum systems to controlling them. In 1982, Richard Feynman proposed quantum computers, machines that use quantum bits (qubits) to perform calculations exponentially faster than classical computers for certain problems. Unlike bits, which are 0 or 1, qubits can be 0, 1, or both simultaneously, thanks to superposition. Quantum entanglement enables secure communication protocols, like quantum cryptography, which could make hacking impossible. What would a world with ultra-secure networks or computers solving problems in seconds look like? In parallel with quantum computing, the second quantum revolution has birthed quantum sensing and advanced quantum materials, technologies that exploit quantum mechanics' precision to transform industries. Quantum sensors, such as atomic clocks and magnetometers, leverage the sensitivity of quantum states to measure time, gravity, or magnetic fields with unprecedented accuracy. For instance, nitrogen-vacancy centers in diamonds enable nanoscale magnetic resonance imaging, revolutionizing medical diagnostics and materials science. Meanwhile, quantum materials—like topological insulators and superconductors—exhibit exotic properties governed by quantum effects, promising energy-efficient electronics and robust quantum computing hardware. These innovations, rooted in controlling individual quantum systems, are already enhancing navigation systems, environmental monitoring, and renewable energy solutions. Just as Heisenberg's matrices decoded atomic behavior, quantum sensing and materials are unlocking new frontiers, bridging fundamental science with global challenges.

"Quantum computers will do for the 21st century what electricity did for the 19th century: transform every aspect of our lives."

— Michio Kaku

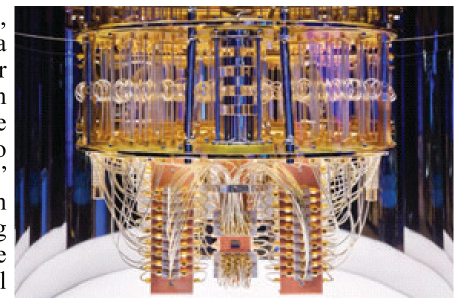


Fig. 5: Inside an IBM Quantum System 2021.

Experimental breakthroughs fueled this revolution. In 1986, physicists like Arthur Ashkin used lasers to trap particles, a technique now central to quantum experiments. Quantum error correction, proposed by Peter Shor in 1995, made quantum computing feasible despite noise. Today, companies like Google and IBM, alongside other quantum research hubs, are racing to build scalable quantum computers. The United Nations' declaration of 2025 as the International Year of Quantum Science and Technology celebrates these advances, urging global collaboration to harness quantum's potential. Why do we need quantum computers when we already have powerful supercomputers? That's a fair question—after all, supercomputers like Frontier and Fugaku are incredibly fast at solving complex problems. But they still follow the rules of classical computing, processing one step at a time using bits that are either 0 or 1. In contrast, quantum computers operate on a completely different principle. They use qubits, which can exist in a superposition of 0 and 1, and become entangled, allowing them to process vast combinations of states at once. This parallelism gives quantum computers exponential speedups for specific problems that would take even the best supercomputers thousands of years to solve. For example, simulating a molecule with 100 interacting particles is nearly impossible on a classical machine, but could be efficiently done on a quantum computer. That's why quantum computing isn't about replacing classical machines — it's about solving a different class of problems that are intractable today.

Fig. 6: A Quantum on Display 2025

When will we have quantum computer in our hands? This is the question everyone is asking. The answer is: *theoretically soon, but experimentally not yet*. We already know how to build quantum computers using superconducting qubits, trapped ions, and even photons. But the real challenge is coherence time—the ability of qubits to stay stable long enough to do useful calculations. The coherence time decides how long qubits can stay in their quantum state before they lose information due to noise or disturbance. Even tiny vibrations or temperature changes can destroy the delicate quantum states. To run useful algorithms, qubits need to remain coherent for at least a few milliseconds, but currently, most systems struggle to reach even that. That's where logical qubits come in. A logical qubit is a stable, error-corrected version of a qubit, built from many physical qubits working together. Why? Because physical qubits are noisy and error-prone. To correct for these errors and keep the quantum information intact, we use redundancy. On average, we need around 1,000 physical qubits to make just one logical qubit. And to run a real-world quantum program — like cracking an encryption algorithm or simulating a molecule — we may need thousands of logical qubits, which means millions of physical qubits. When we increase number of qubits, coherence time decreases sharply, scientists and engineers are improving error correction and coherence times every year, and back in 2023, MIT researchers set a record with a single qubit lasting half a millisecond. That sounds tiny, but in quantum computing, it's progress. Now, coming back to the question, when will you hold one? Maybe not in your room soon, but in special labs and industries within the next decade. But practically, it all depends on improving coherence times, refining quantum error correction, and scaling up the number of physical qubits without losing control. It's a race of engineering, physics, and innovation. And it's a race we can win — with smart minds and steady hands in the lab.

Horizons Ahead: Quantum's Next Century

As quantum theory turns 100, it has achieved amazing breakthroughs—but some deep mysteries still remain. *Where will quantum take us next by 2125?* As quantum theory surprised the 20th century, quantum technologies will surprise the 21st. *"The first century gave us the theory. The next will belong to those who build." Th*e future of quantum technologies is not just bright—it's powerful, and deeply human. From designing life-saving medicines to unlocking the secrets of climate and energy, quantum computers promise to solve problems that today's supercomputers cannot. One of the most exciting frontiers is the rise of *secure Quantum AI*—a fusion of quantum computing and artificial intelligence that could learn and reason faster than ever imagined, while also ensuring data security through quantum encryption. But with such power comes deep responsibility. Who sets the rules? How do we ensure that these tools are used for the benefit of all? Another groundbreaking frontier is the development of the *Quantum Internet*, which aims to enable ultra-secure communication networks based on the principles of quantum entanglement and teleportation. The road ahead demands strong global cooperation, transparent ethical standards, and a commitment to fairness. If guided wisely, quantum technologies and secure Quantum AI can help us build a safer, smarter, and more connected world for the century ahead.

The ultimate goal of physics is to find what is jocularly referred to as a theory of everything, from which all else can be derived. Physicists know something is missing at the top of the tree, because we lack a consistent theory that includes both gravity and quantum mechanics, yet the universe contains both phenomena. Despite a century of remarkable progress, quantum theory continues to raise profound open questions that touch the foundations of physics and our understanding of the universe. Will quantum computers solve climate change or drug discovery challenges? Can we reconcile quantum mechanics with gravity to understand black holes? One of the biggest mysteries is the lack of a complete theory of quantum gravity—a framework that unifies quantum mechanics with general relativity. While quantum theory governs the microscopic world and general relativity describes gravity and the large-scale structure of spacetime, the two remain fundamentally incompatible at extreme scales, such as inside black holes or at the Big Bang. At the cosmic level, questions surrounding dark matter and dark energy—which together make up about 95% of the universe—remain unsolved. Intriguingly, neutrinos, once thought to be massless, may play a key role in unlocking these mysteries. Their tiny masses and oscillatory behavior suggest they might connect the quantum world with cosmological phenomena, offering clues to the early universe, the asymmetry between matter and antimatter, and the structure of dark matter. These deep and unresolved questions remind us that quantum theory is still a work in progress, and its next breakthroughs may reshape our understanding of both the microscopic and cosmic realms.

Another unresolved issue is the true nature of quantum measurement: when and how does a quantum system transition from a superposition of possibilities to a single observed outcome? The mechanism of wavefunction collapse remains a central puzzle, giving rise to multiple interpretations from the Copenhagen

view to many-worlds and objective collapse theories. Some have even speculated about the role of consciousness in triggering collapse—though highly controversial, this idea remains part of ongoing philosophical debate. Quantum mechanics is also pushing beyond physics into biology and space as well. Quantum biology studies how effects like tunneling aid processes like photosynthesis. Could this knowledge transform farming or medicine? In space, quantum sensors might guide interstellar missions, and quantum networks could secure data over vast distances. Projects like the European Quantum Flagship are driving these efforts. What will quantum reveal about life and the stars? Society must also embrace quantum advances. How will schools prepare students for a quantum economy? Events like Quantum Fest 2025 promote public understanding, but reskilling workers is key. Quantum computing's link with AI sparks big questions: Will it solve tough problems or create risks? Could quantum technologies bridge global inequalities, as the UN hopes, or widen them? The International Year of Quantum, launched in Paris in February 2025, calls on scientists, students, and citizens to engage with these questions. Events like Quantum Fest and the Helgoland workshop, attended by Nobel laureates, remind us that quantum's story is still unfolding.

Fig. 7*: Scientific Theories can be organized into a family tree where some are built upon more fundamental ones. For example, classical mechanics can be obtained from special relativity in the approximation that the speed of light is infinite, and hydrodynamics with its concepts such as density and pressure can be derived from statistical mechanics. However, most connections are not so straightforward—while chemistry is, in principle, based on quantum mechanics, the complexity of many molecules often requires practical, empirical methods. Similarly, deriving biology from chemistry or psychology from biology would be even more hopeless in practice.*

PIEAS: Leading Pakistan's Quantum Frontier

At PIEAS, quantum science is more than history—it's our mission. Within our Center for Mathematical Sciences, the Department of Physics and Applied Mathematics has laboratories dedicated to quantum research. We are actively working on both the theoretical and experimental aspects of quantum science to better understand its strange and fascinating nature. Our research covers a wide range of areas, including quantum optics, quantum computing, quantum key distribution (QKD), and optical tweezers–which allow us to manipulate tiny particles with light. We are also exploring quantum machine learning (QML), a powerful new field that combines quantum computing with artificial intelligence to solve complex problems. Our laboratories are well-equipped with modern facilities that support hands-on experiments, helping researchers and students turn theory into practice. To promote knowledge and collaboration, especially during the International Year of Quantum, PIEAS has hosted a series of workshops, seminars, and training sessions. These events bring together experts, students, and enthusiasts to share ideas and learn about the latest developments in quantum technologies. Whether you're interested in solving deep questions about the quantum world or want to develop the technologies of the future, PIEAS provides a strong platform to grow and contribute. We invite passionate minds to join us in exploring the mysteries and promises of quantum science.

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Unsolved Cosmic Mysteries

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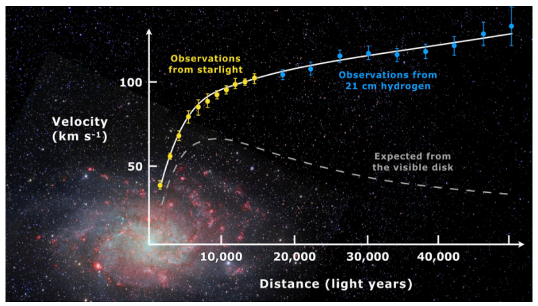
"The known is finite, the unknown is infinite; intellectually, we stand on an islet in the midst of an illimitable ocean of inexplicability. Our business in every generation is to reclaim a little more land."
-T. H. Huxley, 1887 (Courtesy: Cosmos)

The universe is not as simple and consistent with our understanding as Homo sapiens especially physicists (un-beatable creature) want it to be. Every attempt to understand nature in the history of physics reminds us of the paradoxicality and contradiction of natural phenomena with our anticipation – whether it was the mysterious motions of Uranus or Mercury defying Newton's Laws, the complexities of black body radiations, the dilemma of the speed of light, or the structure of the atom. However, such mysteries had puzzled the physicists of the time; human intellect and curiosity not only remained unrevealed but also developed models for accurate predictions of nature. However, the universe seems determined to give us a tough time. Even today, many such mysteries and unsolved problems persist, defying our understanding and resolution, though human curiosity seems to be made for these challenging problems. Let us take a brief look at a few of these mysteries in the realm of Physics.

Dark Matter

When physicists get ready to observe how the universe behaves on a large scale, they look at the universe through the lenses of Newtonian Mechanics or General Relativity, and when observation turns out to be inconsistent, the scientific community either doubts observation itself or the lenses (models) being used. A similar thing happened in 1933 when Swiss physicist Fritz Zwicky looked up in the sky and focused on the Coma Cluster for his study. In his paper, he reported the observed velocities (in the order of thousands of meters per second) of the galaxies using red shift. But when he applied Virial Theorem (assuming that Coma Cluster in stable state) to determine the mass density of the cluster if the velocities of the galaxies should remain in consistence with observation, he found that the density should be hundreds of times greater than that based upon the observation of luminous (visible) matter. "Where is the unseen matter then?" Perhaps he would have asked himself. He called it "Dunkle Materie", meaning "Dark Matter", but ordinary in nature.

But the idea remained unpopular until the 1970s when Rubin and Ford studied rotation curves (plot of orbital velocity vs distance from the centre of the galaxy) of galactic stars. Based upon the visible mass distribution, it was expected that the farther we move from the centre of the galaxy, the lower the orbital velocity of stars should be. But the outer stars were observed to have constant or increasing orbital velocity rather than decreasing with radial distance. If we assume that Newtonian Mechanics is



Rotation curve of spiral galaxy Messier 33 (yellow and blue points with error bars), and a predicted one from distribution of the visible matter (gray line) by Mario De Leo

consistent, such rotation curves can only be explained if the enclosed mass (inside the radial distance) increases even beyond the visible disks of galaxies. That missing matter again breathed life into the problem of dark matter. Similar observations also indicated that there is some missing matter in the universe. For example, the observations of gravitational lensing from the 1980s onward showed that the amount of visible mass is not enough to account for the strong bending of light around galaxy clusters. Beyond that, temperature fluctuations in Cosmic Background Radiation and others could not be explained with ordinary matter alone. Similarly, the simulations carried out in the 1980s based on Newtonian Mechanics and thermodynamics could not produce the observed cosmological structures using only baryonic matter (ordinary matter).

In short, the behaviour of galaxies and cosmic structures was inconsistent with our physical models and observed distributions of baryonic matter. Thus, physicists came up with two approaches: either our Newtonian Mechanics and General Relativity are inconsistent at the intergalactic scale, or these theories are still valid, but some mass is really beyond our sight. Physicists attempted to tackle this challenge from both approaches. Following the first approach, Mordehai Milgrom proposed Modified Newtonian Dynamics (MOND) in which the Newtonian laws were modified at low accelerations which is such a way that they reduced to the standard laws at relatively higher accelerations. MOND successfully explained galaxy rotation curves, but inconsistent with other observations and GR. Later on, its relativistic version, called Tensor-Vector-Scalar Gravity (TeVeS), broke in but faced similar issues. Such models could not explain the CMB observations. Similarly, a strong candidate turned out to be Emergent Gravity, considering gravity is an emergent phenomenon rather than a fundamental force. As we consider temperature to be emergent from molecular motions. But this model failed to account for CMB fluctuations and observations other than galaxy rotation curves.

Approaching the other way around, physicists came up with two types of proposals: either the missing mass is baryonic (ordinary like visible mass) or non-baryonic, assuming Newtonian Mechanics or General Relativity to be consistent. But before we proceed, let us understand how that missing mass should behave. As observations suggest, this invisible mass should have a gravitational effect like ordinary matter, but rarely or never interacts with ordinary matter other way around e.g. through electromagnetic effects or other interactions. That's why it should be non-luminous, making it hard to detect.

Like Zwicky's hypothesis, initially, physicists thought dark matter could be of the ordinary form of matter, but non-luminous. Some proposed that Massive Compact Halo Objects, like black holes, rogue planets, etc., can account for dark matter, but the MACHO and EROS survey projects ruled out this suggestion. Physicists who find themselves in trouble look at neutrinos as a candidate for dark matter, but because of their high relativistic speeds, they cannot account for the formation of large cosmic structures. A suggestion came for nominating primordial black holes as dark matter, but again, the data from Voyager 1 and others ruled it out as a primary component of dark matter. Furthermore, Big Bang Nucleosynthesis already

predicts the observed abundance of ordinary matter. Similarly, Weakly Interacting Massive Particles were supposed to interact with matter through gravity and weak nuclear force, but such particles have not been found yet, even though they were supposed to be detected, for their effects are principally detectable.

Later on, the current best fit model with cold (with slow motion) dark matter and unknown particle nature (non-baryonic) remains the leading hypothesis. It not only explains CMB fluctuations and large-scale structure but also gives an account for the accurate proportion of missing matter. Though it also faces small-scale problems, but not enough to rule it out of the scene. Furthermore, it is incorporated in the ΛCMD (Lambda Cold Dark Matter) model, which is a standard cosmological model based upon GR explaining the large-scale structure and evolution of the universe accurately. Although dark matter is still one of the big mysteries, physicists are still optimistic about finding the origin of so-called Dark Matter.

Dark Energy

The word "Dark Energy" may be fascinating at first sight, but like dark matter, this word has no information in itself, but yes! This energy has a direct relation with the expansion of our universe, the spacetime, to be precise, which possesses deep meaning in itself. Let's see how?

Till the early 20th century, the physicists and philosophers believed that the universe is in static equilibrium without any beginning in time and without any end, because otherwise there would be paradoxical theological and metaphysical questions about the beginning and stability of the universe. Even Newton had to assume infinite static space to avoid any directed motion (contraction or expansion) of the universe, which seemed to be an inevitable consequence of his laws. Einstein's field equations forewarned such a dynamic universe, but Einstein introduced the "Cosmological Constant", denoted by lambda (Λ), in his field equations, counteracting gravity to keep the universe balanced. This constant referred to an anti-gravity force or energy that was built into the very space-time. But later on, it was realized that such an equilibrium would be unstable and ultimately lead to continual expansion or contraction again. Only Friedmann was taking Einstein's field equations seriously and predicted the expansion of the universe at different rates depending on its mass-energy density. According to his model, if the density of universe is more than a critical value, it will keep expanding forever but its rate should decrease due to the gravity, but if the density is lower than critical value, it would expand to an extend and start contracting again, leading to gravitational collapse (Big Crunch). In 1929, Edward Hubble discovered that the universe is expanding when he directed his observatory to the distant extra-galactic supernovae (what we know as galaxies today), and Einstein's anti-gravity constant with built-in anti-gravity energy of spacetime turned out to be a great blunder. Now, scientists sought to determine which of Friedmann's cosmological models best describes our universe; whether it will keep expanding at a decreasing rate or will ultimately start contracting at some point in time.

But the real problem was waiting ahead when, in the 1990s, two independent teams studying Type Ia supernovae found that these stellar explosions were dimmer than expected, implying that they were farther away than models predicted. It turned out to be a clear indication that the expansion of the universe is accelerating over time rather than decreasing – a new challenge posed by the universe to physicists. It was the moment when it was realized that there is something hidden from sight, causing the acceleration of expansion, against the gravity, some unknown force (and corresponding energy). The term "Dark Energy" soon became a placeholder for the unknown force responsible for this acceleration. Subsequent observations from the CMB and large-scale galaxy surveys further indicate that if such energy exists, it contributes about 70% of the energy density of the cosmos.

But where does this energy come from? The simplest explanation to this question lies in something abandoned in the past. Yeah! The very Cosmological Constant of Albert Einstein. The constant, which referred to an anti-gravity force. As this force or energy is the property of space itself, its concentration is not diluted as space expands because in the field equation of GR, the energy density associated with the cosmological constant remains constant over time, indicating a constantly accelerated expansion of the universe. The value of this constant can be adjusted such that it fits the observational data elegantly, but its unexpectedly small value poses theoretical puzzles of fine-tuning. Alternatively, the Quintessence model considers a scalar field coupled with spacetime, and the potential energy of this field causes the observed accelerated expansion. Unlike the cosmological constant, this quintessence field is not static but slowly evolving with time and potentially able to solve fine-tuning problems. But it introduces additional parameters that are yet to be confirmed.

But dark energy is the requirement of General Relativity to explain the observed accelerated expansion. Thus, it is conceivable to doubt the universality of general relativity at cosmic scales and that the modifications in gravitational theories will eliminate the need for dark matter. Similar models were presented, for example, f(R) Gravity, which brings suitable changes in GR, which naturally leads to accelerated expansion and others like Massive Gravity, DGP Braneworld Gravity, etc. But these theories often predict deviations from GR that are not observed in high-precision experiments. For example, the measurement of the speed of gravity ruled out many of such theories. Nevertheless, the very ΛCMD (Lambda for dark energy) model is a widely accepted cosmological model today. It explains the universe's expansion using Λ (the cosmological constant) as dark energy. The model is strongly supported by multiple observations. As our observational techniques improve and our theoretical frameworks evolve, the persistence of certain models reflects their ability to address both the empirical data and the conceptual puzzles posed by the universe.

Time Travel Through Wormholes

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The concept of time travel, the desire to transcend the linear progression of time, was once confined to the realm of science fiction. In the present day, thanks to advancements in modern physics, the concept of time travel is no longer confined to the realm of fantasy but is being explored as a theoretical possibility. The core of this concept revolves around wormholes, theoretical tunnels that traverse spacetime, as predicted by general relativity. In this article, we delve into the scientific principles behind wormholes, the mechanics of time travel, and how these groundbreaking theories surprisingly align with concepts alluded to in the Quran and Islamic tradition. We also delve into the captivating er=epr conjecture, which proposes a profound link between quantum entanglement and wormholes, providing a tantalizing glimpse into the potential structure of our universe.

Introduction

The clock shapes our lives. We often fail to appreciate the passage of time, assuming it moves consistently and irreversibly from the past to the future, without considering its unique flow.

What is the essence of time? Einstein's groundbreaking theory of general relativity revolutionized our understanding of time by demonstrating that it is not absolute, but rather influenced by the presence of mass and gravity, causing it to bend and stretch.

This realization led to the consideration of time loops and warps in the fabric of the cosmos, which could potentially enable time travel. One of the most promising models for such travel involves wormholes: theoretical bridges that might connect two points in spacetime, and possibly even two different moments in time.

Wormholes:

In 1935, Albert Einstein and Nathan Rosen introduced the concept of wormholes, also known as einstein-rosen bridges, as potential solutions to Einstein's field equations. These structures mathematically represent a tunnel that connects two distant regions of spacetime. Initially, the Einstein-Rosen bridge was deemed non-functional due to its instability, making it impossible for anything to cross. However, subsequent modifications proposed methods to stabilize the bridge.

In 1988, physicists kip thorne and michael morris delved into the idea of traversable wormholes. They hypothesized that these structures could be kept open using exotic matter, a type of matter with negative energy density, which is allowed by quantum theory but has never been observed in significant quantities. If one end of a wormhole were accelerated to a speed close to that of light and then brought back to rest, time dilation would cause that end to be "younger" than the stationary end. This creates a temporal gap between the two mouths. An object could pass through one end and reappear from the other before it entered — creating the illusion of time travel.

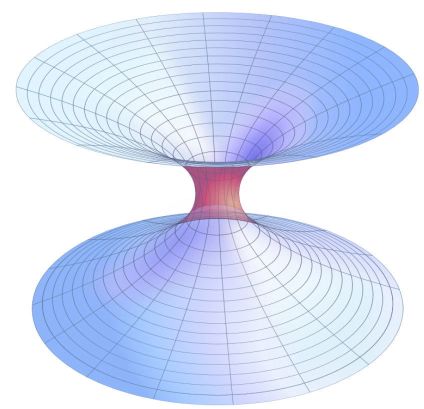


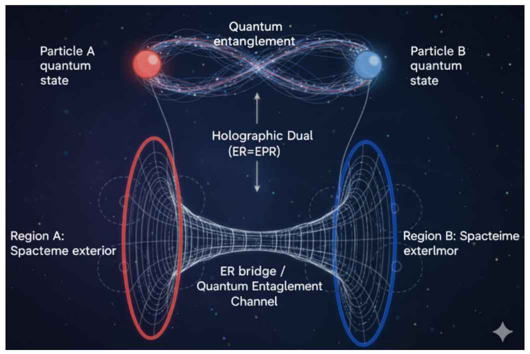
Fig. "Embedding diagram" of a Schwarzschild wormhole. Credit: Wikipedia

Theoretical framework:
Wormholes are explained by Einstein's general theory of relativity, which provides the mathematical framework for their existence. The theory states that:

"The mass and energy of an object determine how space and time are curved, and in turn, curved spacetime dictates the motion of matter.".

In certain extreme circumstances, this curvature can lead to the formation of shortcuts wormhoies through the fabric of spacetime. Nevertheless, relativity alone cannot account for all occurrences in the vast expanse of the universe. This is where quantum mechanics enters. The quest for a unified theory of quantum gravity, which combines the principles of relativity with quantum physics, is where some of the most groundbreaking concepts about time travel originate.

Quantum entanglement and the EPR conjecture.
One of the most enigmatic and perplexing phenomena in quantum physics is entanglement. When two particles become entangled, measuring one immediately influences the other, regardless of the physical distance separating them — a concept Einstein famously referred to as "spooky action at a distance.".



In 2013, theoretical physicists Juan Maldacena and Leonard Susskind put forth the er=epr conjecture. This concept suggests that wormholes and entangled particles are two different manifestations of the same underlying phenomenon. In simpler terms:

"Particles that are linked by minuscule tunnels may be entangled."

This groundbreaking concept suggests that spacetime could be interconnected through networks of entanglement, and wormholes serve as the visual representation of this quantum connection. In this perspective, entagalment is not just a mysterious connection-it is the fundamental force that weave the fabric of the universe. This concept has significant implications for time travel: if wormholes and entanglement are interconnected, it implies the potential for altering time using quantum methods.

Time travel paradoxes and multiverse resolutions.
Although wormhole-based time travel may seem theoretically appealing, it presents significant paradoxes that need to be addressed. The most well-known paradox is the grandfather paradox — what would occur if you traveled back in time and prevented your grandparents from ever meeting?.

Physicists have suggested multiple solutions. One of the many interpretations of quantum mechanics is the many-worlds interpretation, which proposes that every decision creates a separate universe. Within this framework, rewinding time generates a new timeline, preventing any contradictions.

Stephen Hawking put forth the chronology protection conjecture, which suggests that the laws of physics prevent time travel on a large scale, ensuring the preservation of causality. Although there is no definitive answer, these theories push the limits of our understanding, questioning the nature of time and reality.

Quranic parallels:
Remarkably, concepts of time relativity and multidimensional journeys are found in the Quran and Islamic tradition. Although not scientific texts, these references metaphorically align with modern physics, providing profound spiritual insights.

As in Surah Al-Kahf, Ayah 25
And they remained in their cave for three hundred years and exceeded by nine.(18/25)

This verse reflects a miraculous time shift — the sleepers stayed in the cave for over three centuries, yet felt as if they had slept only part of a day. This aligns with modern physics concepts like time dilation and wormholes, where time passes differently in different regions of spacetime. It hints that Allah's control over time and space surpasses our linear understanding, revealing the possibility of divine shortcuts through time — like wormholes.

Verse from surah al-hajj (22:47):
"And indeed, a day with your Lord is like a thousand years of those which you count."
This verse reflects the relativistic concept that time is not fixed.

The quran also contains stories with time-warping characteristics. One example is in surah albaqarah (2:259), where a man is caused to die for a hundred years and then resurrected, having felt only a moment had passed. This is remarkably similar to time dilation, where time appears to pass at different rates for observers in different frames of reference.

Even more compelling is the miraculous journey of Prophet Muhammad (SAW), known as the isra and mi'raj, which took place during the night. In a single night, the prophet embarked on a journey from Mecca to Jerusalem, ascending through the heavens — an experience that challenges our understanding of time and space. Upon their return, many doubted the possibility of such a journey, dismissing it as an impossible feat. However, for those who hold strong religious beliefs, this journey represents a reality that surpasses physical boundaries, similar to what modern physics suggests through the concepts of wormholes and extra dimensions.

Although these narratives are extraordinary and not reliant on physics, their similarities with relativity and time manipulation are intellectually captivating, demonstrating that the concept of time's fluidity is not unfamiliar to Islamic thought.

Advancements and Innovations
Recent developments in wormhole physics have expanded the scope of both theoretical studies and observational investigations. New solutions derived from classical general relativity have suggested the possibility of stable, traversable wormholes that do not necessarily require exotic matter, challenging earlier assumptions. In parallel, extensions of general relativity, such as Gauss-Bonnet gravity and scalar-tensor theories, are being explored to account for the existence of such wormholes in more diverse settings. In observational cosmology, emerging techniques, including gravitational lensing, the study of accretion flows, and anomalies in stellar motion near galactic centers, are becoming potential tools to detect and confirm the presence of wormholes. At the cutting edge of technology, advancements in particle accelerators, quantum simulations, and astronomical instruments are providing deeper insights into the properties of extreme spacetime geometries.

Additionally, theoretical concepts like thin-shell and virtual wormholes are being examined at the Planck scale, opening doors for future breakthroughs in transitioning from microscopic to macroscopic wormhole structures. While practical realization of wormholes remains a distant goal, the rapid progress in both theoretical models and observational capabilities is signaling a new era of scientific exploration, bringing concepts once deemed speculative into the realm of serious study.

The bridge between science and spirit.
Concepts like wormholes, time travel, and entanglement are not just subjects for physicists — they delve into the fundamental nature of existence itself. They challenge our preconceived notions, broaden our perspectives, and compel us to confront the boundaries of what we perceive as real.

Remarkably, as we venture into these uncharted territories, we discover echoes in ancient scriptures like the Quran — not as scientific manuals, but as sources of timeless wisdom. The Quran's allusions to time dilation, multidimensionality, and timelessness harmonize with contemporary scientific theories, emphasizing that truth often emerges from the convergence of science and spirituality.

The possibility of constructing wormholes or inventing time machines remains uncertain. However, in our quest to comprehend the structure of the universe, we embark on a journey that dates back to the dawn of human existence — a journey that encompasses the pursuit of knowledge, the affirmation of beliefs, and the establishment of a profound connection with the fundamental truths of the cosmos.

Beyond the Clock: Understanding Time

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Physics is not just the study of matter and energy, It is the language we use to describe the universe. And within this language, nothing is more profound, more quietly mind shaking than the idea that time isn't what we think it is. That light doesn't just move fast it defines the limits of reality. That the universe, rather than being a stage on which things happen "is "the thing happening.

We are taught early on that space and time are separate, space is where things are, time is when things happen. But what if that very distinction is a mental illusion? What if space and time are really two different aspects of a single thing? And what if our everyday experiences, our clocks, even our sense of 'now' are just poor approximations of something deeper? This is not philosophy. It's physics. And it starts with light.

Light is strange. It has no mass, yet carries energy. It can push particles, yet has no rest frame. If you were somehow able to ride alongside a photon, time would freeze. The universe would appear flat, collapsed along the axis of your motion. This isn't science fiction, it's a direct consequence of Einstein's theory of special relativity. Photons don't experience time. They are born and absorbed in the same instant, as far as they are concerned.

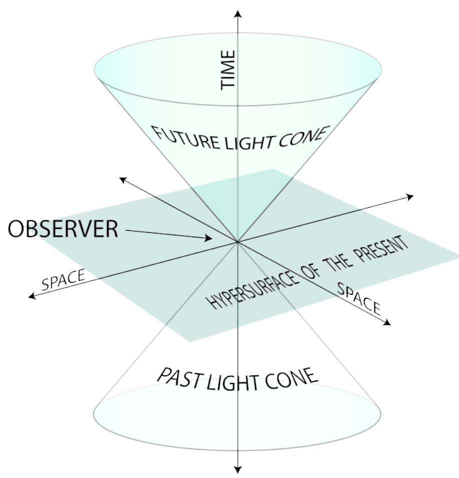
This realization invites a strange image that is, when light travels from a distant star to your eye it doesn't take thousands of years from the light's perspective. From the photon's "point of view" it begins and ends its journey instantly. This concept builds a very strange perception about time.

Our perception of the "present" is surprisingly not very correct. The equations describing the universe are time symmetric. They don't care whether time flows forward or backward. In fact, there is no universal "present" no single point of time that everyone, everywhere, would agree upon. What is "now" for you on Earth might be "in the past" or "in the future" for someone near a black hole. This isn't a metaphor, it's measurable and verified.

This idea challenges everything we know about how time works. If light doesn't experience time, and if time isn't the same for everyone, then what does this mean for our understanding Of the universe? It forces us to rethink not only the nature of time but also the entire structure of reality itself.

In relativity, time is not an independent. Time is a dimension of spacetime, tied to the other three spatial dimensions. Together, space and time form a unified fabric that can bend, stretch, and warp depending on mass and energy. This is where the depth of Physics lies, the realization that space and time are not fixed or absolute.

To understand this, let's consider the concept of light cones. A light cone represents the limit of how far light (and any causal influence) can travel through spacetime from a given event. This is crucial because it shows the boundaries of what can be observed or influenced by a particular event.

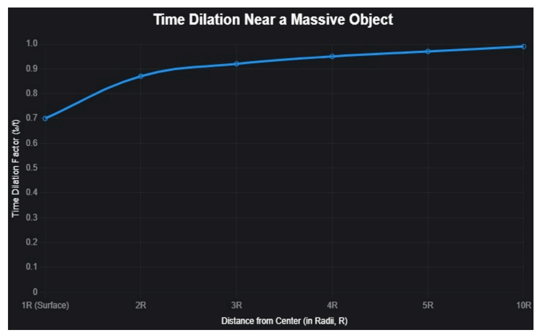


The light cone helps us visualize how time and space are connected the shape of the cone is determined by the speed of light, meaning that the farther an event occurs from us in space, the longer it takes for light to reach us. This also means that different observers, depending on their position and velocity, may disagree on the order of events .what one person perceives as happening before another, might appear the reverse to someone moving at a different speed.

The "Relativity Of Simultaneity" is a direct result of this framework. The concept that events that are simultaneous in one frame of reference may not be simultaneous in another is a very strange consequence of special relativity. This directly challenges the classical notion of "now" the idea that there is a single, universal moment in time that all observers can agree upon.

According to relativity, this isn't true. Time doesn't flow in the same way for everyone, everywhere. Time is relative, and what makes the present for you is not the same as what makes the present for someone moving at a different velocity or in a different gravitational field. So we can say the very nature of reality, as experienced by different observers, is not the same.

When we combine this with "General Relativity", the picture becomes even more complex. General relativity tells us that mass and energy warp spacetime, and this warping is what we perceive as Gravity. The stronger the Gravitational Field, the greater the warping of spacetime, and the more time is distorted. For instance, time passes more slowly near a massive object like a planet or a black hole. This effect, known as "Gravitational Time Dilation" has been experimentally verified, and it shows us that time is not just a linear progression. It is affected by the very structure of spacetime itself.



This presents a shift in how we view time, it's not an absolute, independent force but a dimension tied with the fabric of space, and one that is influenced by the very forces of the universe. The idea that time can be bent, warped, or even stretched based on the motion of objects or the presence of mass is something that was inconceivable before Einstein's theories.

But now, it's a proven fact that shapes the foundation of modern physics.

So, what does this mean for our understanding of the universe? If light, the fastest thing in the universe doesn't experience time, and if time is not absolute but relative to the observer, then our perception of reality is fundamentally flawed. The very concept of "now" is an illusion, a simplification of a far more complex reality. And yet, this doesn't make the universe any less real. In fact, it makes it more fascinating. The universe is not a static stage on which events happen it is the very process of those events happening. Time isn't a constant, and space isn't a background. They are interconnected by the movement of mass and energy.

And yet for all our understanding, time remains one of the biggest unresolved puzzles in physics.

The core issue is this, in Quantum Mechanics time is treated as absolute a background parameter that ticks forward universally. But in General Relativity, time is dynamic effected by gravity and geometry. These two foundational theories of modern physics cannot agree on what time actually is. This conflict becomes unavoidable when we try to understand the universe at the smallest scale, the Planck scale where both quantum effects and spacetime curvature are significant. Physicists working on quantum gravity, string theory, and loop quantum gravity are all trying to reconcile this contradiction. Some theories suggest that time might be emergent not fundamental at all, Others propose that time might "disappear" entirely in a true theory of "Quantum Gravity".

Until we unify these two frameworks, we cannot say with certainty what time actually is. Does time flow, or is it static and we simply experience it as change? Is there a beginning and an end, or is time an illusion altogether? These are not philosophical questions, they are problems in theoretical physics.

So the" Haqeeqat "(Reality) of time, as it stands today has two sides, on one hand, relativity has shown us that time is not universal or absolute. On the other, quantum mechanics refuses to let go of the classical idea of a ticking clock. Somewhere between the two might lie a deeper truth one we haven't yet uncovered.

Quantum-Classical Correspondance

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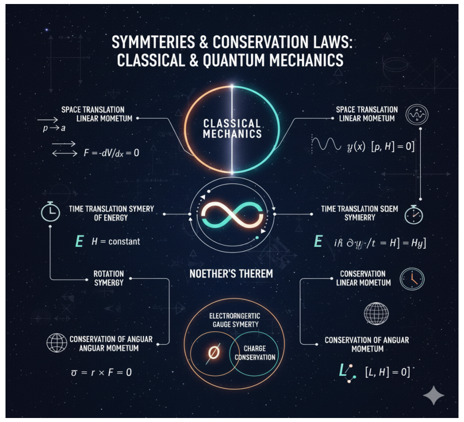
Introduction
The quantum-classical correspondence is a central theme that bridges two seemingly distinct worlds — the quantum realm, governed by the strange rules of uncertainty and superposition, and the classical realm, dominated by deterministic trajectories and well-defined states. At first glance, these two domains appear incompatible: the quantum world is often described as unpredictable and probabilistic, while classical mechanics follows precise laws where cause and effect are clear. However, the deeper we explore the relationship between quantum and classical physics, the more apparent it becomes that they share a fundamental spirit of describing the physical universe, albeit from different perspectives.

The correspondence principle, originally introduced by Niels Bohr in the early 20th century, posited that quantum mechanics should reduce to classical mechanics in the appropriate limit — specifically when the action involved in a system becomes large compared to Planck's constant. This principle was crucial in reconciling quantum mechanics with classical mechanics, offering a transition from quantum systems to classical systems as the quantum numbers become large. But what does it really mean for these two frameworks to share the same spirit? To explore this, we must look at the deeper structures and principles that govern both systems.

The Role of Symmetries and Conservation Laws
One of the central unifying ideas between quantum and classical mechanics is the concept of symmetry. In both frameworks, symmetries form the back bone of the physical laws that govern the universe. In classical mechanics, these symmetries are manifested in conserved quantities such as energy, momentum, and angular momentum, derived from Noether's theorem. In the quantum world, symmetries take on a slightly different character but are still foundational. For example, the symmetry of time translations in quantum mechanics gives rise to the conservation of energy, a principle that mirrors classical physics.



The interplay between symmetry and conservation is a thread that runs through both classical and quantum theories. In classical mechanics, the Hamiltonian function, which describes the total energy of a system, remains constant in time for closed systems, leading to energy conservation. Similarly, in quantum mechanics, the time evolution of a quantum state is governed by the Schr¨odinger equation, where the Hamiltonian operator plays a crucial role in dictating the system's dynamics. Despite the apparent differences in the mathematics of quantum mechanics and classical mechanics, both frameworks respect the principle of energy conservation.

Quantum-Classical Transition: A Geometrical Perspective
To delve deeper into the connection between quantum and classical worlds, we must consider the geometrical structures that govern both domains. In classical mechanics, the phase space — a space defined by the generalized coordinates and momenta of a system — is a central concept. The evolution of the system can be described as trajectories moving through this phase space, and the preservation of phase space volume during time evolution is governed by Liouville's theorem. This theorem guarantees that the phase space volume remains constant in Hamiltonian mechanics, meaning that the behavior of a system is reversible and that information about the system's state is preserved over time.

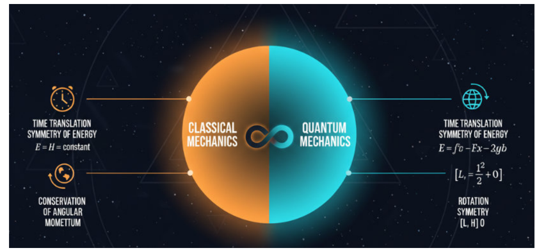
In quantum mechanics, the phase space concept is slightly more abstractbut still plays a role, especially when considering the Wigner distribution, which is a quasi-probability distribution that maps quantum states onto phase space. This distribution can be used to recover classical results from quantum systems in certain limits, further highlighting the connection between the two domains. The geometric nature of quantum systems, governed by symplectic geometry and the principles of phase space conservation, mirrors the classical treatment but with additional quantum-specific nuances.

The Role of Reversibility and Non-Crushing Behavior
The principle of reversibility is another key idea that unites quantum and classical mechanics. In both frameworks, physical systems exhibit reversible behavior under ideal conditions. This means that, for isolated systems, the system's trajectory through phase space is not destroyed or "crushed" over time. In classical mechanics, the preservation of phase space volume — as guaranteed by Liouville's theorem — ensures that no information about the system is lost. Similarly, in quantum mechanics, the time evolution of a quantum state governed by a unitary operator preserves the norm of the state, ensuring that the information encoded in the system is not lost.

This preservation of information is at the heart of the no-cloning theorem in quantum mechanics, which states that an arbitrary unknown quantum state cannot be perfectly copied. The quantum world may have probabilistic outcomes, but the overall framework preserves the integrity of the system's information, akin to the determinism seen in classical mechanics. Whether it is through the Hamiltonian equations in classical mechanics or the unitary time evolution in quantum mechanics, both frameworks respect the symmetry of reversibility, where the flow of time does not erase the past but instead conserves the state of the system in a manner that respects the underlying geometry of phase space.

Quantum-Classical Correspondence and the Foundations of Reality
At a more philosophical level, the quantum-classical correspondence points to a profound unity in the way we conceptualize physical reality. The classical view, with its deterministic trajectories and well-defined states, reflects a world that is comprehensible and predictable. In contrast, the quantum world, with its probabilistic outcomes and wavefunctions, introduces a level of uncertainty and complexity that challenges our traditional understanding of reality. Yet, the correspondence principle suggests that, in the limit of large quantum numbers, quantum mechanics converges to classical mechanics, indicating that both frameworks describe the same underlying reality but through different approximations.

This perspective is particularly important when considering the measurement problem in quantum mechanics — the question of how a quantum system with a superposition of states collapses into a single classical outcome upon measurement. The quantum-classical correspondence provides a bridge between these two worlds, offering a way to



understand how classical outcomes emerge from quantum systems under certain conditions. This idea has significant implications for both the philosophical interpretation of quantum mechanics and the practical application of quantum technologies, where understanding the transition between quantum and classical domains is key to unlocking the power of quantum computation and quantum-enhanced machine learning.

Conclusion: Same Spirit, Different Perspectives

In conclusion, the quantum-classical correspondence represents more than just a technical overlap between two frameworks; it embodies a deeper unity in how we understand the laws of nature. Both quantum and classical mechanics share a common spirit — a desire to describe the world through symmetries, conservation laws, and reversible transformations. While the mathematical tools and interpretations differ, the underlying principles that govern the dynamics of both systems reflect a shared framework of understanding. The correspondence principle, through its exploration of phase space and conservation, demonstrates that quantum and classical mechanics are not opposites but are, in fact, two sides of the same coin — complementary perspectives that together provide a more complete picture of the universe.

Life in Quantum Multiverse

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Envision a reality where every choice you've ever made every alternative not pursued actually exists in a parallel universe. The concept of the quantum multiverse is both bizarre and exhilarating. Based on the many worlds interpretation of quantum mechanics, the theory suggests that every quantum event leads to the creation of new, branching realities. Life, in this perspective, is not limited to a single universe but extends infinitely across numerous realms where variations of you exist, each living out different possibilities. The concept of a multiverse is no longer confined to the realm of science fiction it is a real possibility that has emerged from the cutting-edge advancements in modern physics.

The idea first took root when physicist Hugh Everett proposed that instead of collapsing into one outcome, the quantum wave function splits, creating a separate universe for every potential result. This many worlds interpretation' implies that reality is a constantly branching tree, each branch as real as the next. As Everett stated in 1957, 'all possible outcomes of quantum measurements are physically realized in some 'world' or universe.' Though controversial in its early days, the theory has gained credibility as quantum experiments continue to reveal the non-classical behavior of particles.

Michio kaku, co-founder of string field theory, has expanded this vision of the multiverse. In his book parallel worlds, he writes, 'in some sense, the multiverse is no stranger than the idea that earth is not the center of the universe.' He suggests that the universe we observe may be just one bubble in a vast cosmic foam, each bubble governed by different physical laws a view compatible with the "string theory landscape".According to this theory, string theory allows for 10^{500} different possible vacuum states, each corresponding to a different universe with unique fundamental constants. Our universe may simply be one of the rare bubbles where conditions allow for life.

Life in this myriad of universes would be incredibly varied. It is possible that in certain alternate realities, evolution followed a different path where consciousness arose in silicon-based lifeforms or civilizations developed without ever creating the wheel. In some cases, the laws of physics may function in ways that are beyond our comprehension. Although these ideas are speculative, they are based on rigorous mathematical principles and are supported by quantum phenomena that challenge our classical understanding.

One such occurrence is quantum entanglement. When particles become entangled, their states remain connected regardless of the physical distance separating them. Change the state of one, and the other responds instantly, a feature Einstein famously called "spooky action at a distance." Entanglement supports the notion that at a fundamental level, the universe or multiverse is an interconnected whole. If particles that are entangled can instantly exchange information across vast distances, it is possible that entire universes are interconnected through hidden dimensions of quantum reality.

This brings us to the idea of quantum teleportation, a procedure where the quantum state of a particle is transported to another particle over a distance. In 2017, Chinese scientists achieved a significant milestone by successfully teleporting quantum information from Earth to a satellite in orbit, marking a groundbreaking experiment. Although we are not yet capable of teleporting humans, this breakthrough demonstrated that quantum states can be reliably transmitted over long distances. Is it possible that these principles could one day facilitate communication or even travel between parallel universes? Although speculative, this idea is based on a growing body of evidence that supports the reproducibility of experimental outcomes.

However, the origin of our own universe remains a mystery. According to the big bang theory, the universe originated from a singularity approximately 13.8 billion years ago. However, this scientific explanation may not necessarily contradict spiritual or philosophical beliefs. The Quran explicitly states: 'indeed, your lord is Allah, who created the heavens and the earth in six days' (surah al-a'raf 7:54). These six days are considered to be distinct stages of creation, each holding immense importance that surpasses human understanding. Rather than undermining science, such descriptions may align with the staged unfolding of cosmic evolution.

Surprisingly, the quran also suggests the idea of an expanding universe, which is similar to what modern cosmology proposes.In Surah Adh-Dhariyat 51:47 49 "And the sky We have built with power, and indeed, We are expanding it. And the earth We have spread out what a perfect spreading! And there We have created of every kind a pair, so you might be reminded."This aligns with Edwin Hubble's 1929 discovery that galaxies are moving away from one another, and that the universe is expanding. If the fabric of space is expanding in our universe, it is possible that the same phenomenon is occurring in other parts of the cosmos. According to the eternal inflation theory, our universe is like a bubble in a never-ending inflationary process, where new bubbles new universes are continuously being created.

At the crossroads of science and spirituality, lies consciousness the enigmatic puzzle. What is the phenomenon that enables us to have self-awareness and perceive the world around us? Some scientists and philosophers suggest that consciousness is not merely a result of brain chemistry but an intrinsic component of the universe. This resonates with the concept of panpsychism, which proposes that consciousness is present in all matter, and quantum consciousness theories that suggest the mind could be interconnected with the entire universe. Roger Penrose and Stuart Hameroff propose in their orchestrated objective reduction theory that consciousness emerges from quantum computations occurring within the brain's microtubules a radical, yet increasingly researched, hypothesis.

Michio kaku also explores the notion of a 'cosmic consciousness.' In the future of the mind, he defines consciousness as 'the process of creating a model of the world using multiple feedback loops in various parameters.' He speculates that advanced civilizations may possess such high levels of consciousness that they can manipulate space-time and even create new universes what he calls 'type iv civilizations.' These ideas blur the boundaries between physics, neuroscience, and metaphysics.

This brings us to a philosophical realization: perhaps life is not a solitary struggle in a cold, indifferent universe but a participatory process in an ever-unfolding multiverse. Every choice we make, every thought we hold, might influence not just this reality but many others. The ancient idea that the observer creates reality finds resonance in quantum mechanics. The double-slit experiment, for instance, shows that observation collapses wave functions into particles. In a multiverse context, each act of measurement could correspond to a different path taken a new universe born.

Even the study of the past reflects this progression of knowledge. In the past, classical physics believed that the universe followed a deterministic and objective path. Then came quantum theory, revealing that at the most fundamental level, reality is uncertain and influenced by the observer. Today, the pursuit of a theory of everything a comprehensive framework that integrates quantum mechanics and general relativity continues to be one of physics' most formidable challenges. Scientists are actively investigating various theoretical frameworks, such as string theory, loop quantum gravity, and emergent spacetime models, in their pursuit of confirming or refining our understanding of the multiverse.

Simultaneously, recent breakthroughs in quantum computing and simulation provide intriguing glimpses into parallel quantum realities. Scientists are constructing systems that mimic multiverse like environments, enabling us to observe how realities change when subjected to various conditions. These aren't just hypothetical scenarios anymore they're tangible, measurable, and growing in their capabilities.

In this extensive journey, the significance of humanity may surpass our expectations. We are not mere spectators, but active contributors to the grand story of the universe. Our awareness, curiosity, and capacity for wonder are not exceptions they may be the universe's way of becoming aware of its own existence. In the quantum multiverse, life is not bound by the constraints of biology or restricted to the planet earth. It is a dance of endless possibilities, a symphony of realities where anything can happen, and where every person has the potential to become a gateway to infinite creation.

What is existence in the many-worlds reality? It is the meeting point of science and spirit, matter and mind, potential and existence. It is not just a concept, but a reflection mirroring our identity, potential, and the countless possibilities that lie ahead in our lives.

A Floating World

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How nice it is to meet a person who offers you to change one law of this world. Isn't it so cliché and a fairy tale kind of thing to happen?!!

Yes! So cliché and so out of this world experience. He can't believe he faced such kind of situation and what good he did to deserve this honor. Is he so special or he is in good books of God?

ALEX!! ALEX!!

His train of thoughts was interrupted by a classmate who was calling his name repeatedly. He took a deep breath and realized he is still sitting in his lecture theater with 100 other students, and Sir Robert Plank was teaching ODEs. Alex was wondering where he heard that name and then remembered his father was talking nonstop on a Christmas dinner about *PDEs*, the father of *ODEs*. His mind again went back to the event happened to him couple of days.

Alex is 16 year old, studies at "*Gravitas Academy"*, one of the best colleges in *Newtonsville.* He is an ordinary student but curious and enthusiast by heart. His teachers have high expectations from him because of his background. But he is always struggling with his studies and need help from his classmates for exam preparation. His parents, renowned physicists, his mother is a theoretical physicist and father is experimental physicist. They

have a norm of discussions of their ongoing experiment on a dinner table. All time extroverted Alex is an introverted and keen in front of his parents. He is all ears whenever they discuss their findings, inferences and theories. And that's the only normal family time for Alex.

On a boring Thursday after Easter holidays, Alex was sitting on a bench on campus under a tree. He was annoyed by his parents always being busy and not giving him time and suddenly got hit on his head. That hit was enough to make him black out for a while. After coming back to his sense he saw his surroundings and realized he was hit by an apple and he is sitting under an apple tree. He laughed at the irony. He always thought Newton was so free to think about gravity after seeing a fallen apple instead of devouring it. So he did the opposite and

start eating it. While eating the apple, his mind kept wondering about the *Newtonsville* and the Newton and his laws..
Aghh!
He screamed in frustration. The taste of apple turned bitter on these thoughts and he stopped eating and started staring at the apple. As if this apple was the reason behind Newton's fame and law of gravity. He thought Newton's discovery wasn't an extraordinary one, there's nothing new, everything falls down and as these stupid folks started talking about gravity just to make things complicated. Enough of science discussion he thought. He should rest and enjoy as he had used his enough mind in school for the day.

A 50 years old man, grey hair with a Dutch mustache came and asked permission to sit with him on bench. Alex hesitantly allowed him to share the

bench with him, and started observing him. He has seen him occasionally on campus sitting with multiple teachers and students and discussing different theories. He asked that person his name to start the conversation. That grey haired man with a Dutch mustache introduced himself as *Carl*, and they started chatting about nature and topics started to flow. Alex started to like the Carl in the first meeting. There was something mysterious yet familiar about him. He can't point out that for now.

Alex got impressed to know that Carl can speak multiple languages. So he started to learn new languages from him. Carl becomes the new routine for Alex. They daily meet under the apple tree on campus and started to exchange ideas and different topics. There was evident difference in age between the two but Alex was happy to have a knowledgeable friend who is open to his multiple theories which he couldn't share with anyone before.

One day, Alex was annoyed which is not common.

He was upset with this world or his boring life, Carl asked him what one thing he wants to change about this world
Carl ask him
Was willst du?
Alex responded with confusion as he didn't understand what he was trying to say. Seeing his confusion he offers him that he can change one rule as per his command. What does he want him to change?

Alex changed the subject by asking him what language; he was speaking earlier as they didn't talk in this language before. He was just curious and excited at the same time. Carl nodded gently and said it was German and I knew a few other languages, which you don't know about. *"Like what? I know you know Latin, French and Spanish. What else?"* Alex asked.
"Arabic, Turkish, Urdu, Hindi, Farsi" Carl replied.
"Okayyy! Stop! You don't need to boast!!! I know you are very much capable" Alex shouted excitedly. Carl remained silent and patient. Alex asked him to spoke something in Arabic as he fascinated by Arabic so much.
"Azizi, lam tukhbirni madha tureed an tughayyar?"
Alex's face turned red like a cherry as all blood rushed to his face after listening the word *Azizi.* Seeing his crimson red face and his hesitation from the topic, Carl offered him time to think about it and meet him tomorrow.
Now sitting in Lecture Theater and Thinking about one law, one phenomena that he want to change. *'What could be'?* He questioned himself again and again until the bell rang and he left for home instead of meeting Carl at their usual spot. After carefully thinking about this whole weekend at home, something popped in his mind. Yes he got it!! He shouted excitedly. He decided what rule he just want to change so he can get rid of studies and boring school. He slept happily that night as he has nothing for study if that person can change that one law that he has in his mind. Eagerly waiting for the tomorrow to go to campus and meet Carl.

After his packed schedule and classes for the day he went to their usual spot to meet Carl. He waited for two hours but Carl didn't come. He left disappointed for home.

Next day he went to their usual spot and found Carl sitting there. He was happy to meet him. Carl asked him whether he has decided about which rule he wanted to change. Alex whispered the rule. He did not believe the Carl even he said,
""Sirf aaj raat ka intazar karain, payaray!"

Alex asked what he just said and what language is this?
It's Urdu, said Carl nonchalantly, and stood up from the wooden bench and started moving his body away from that curious and now exhausted boy. Alex thought himself of fool for wishing something like that as he just got pranked.

Next morning, Alex blinked against the soft light streaming through his bedroom window. Something felt different. Lighter. As he sat up, his feet didn't touch the floor — they hovered. A slow grin spread across his face.

"It's Wednesday," he whispered, the words bubbling with excitement. The first day of his wish come true
'A world where gravity only works for Tuesday'
Alex had always been fascinated by the cosmos, dreaming of a place where he could float like an astronaut. Now the rules of gravity had shifted… at least in *Newtonsville*.
Alex floated toward the ceiling, brushing his hand against the light fixture. "No gravity," he said. "Perfect." He pushed off gently, gliding through the air like a balloon in slow motion. Outside, other residents of *Newtonsville* were discovering the same thing. Mrs. Penelope, the baker, flailed midair trying to chase her floating dough. Kids bounced between rooftops like super-powered fleas. The only thing anchoring anything to the ground was memory.

Since gravity was gone, objects and people obeyed Newton's First Law — inertia. Once you pushed off, you'd keep moving unless something stopped you. Without gravity pulling things down, friction and air resistance were the only forces in play — and they were weak.

By next day, people had started to adjust. Alex met his best friend, Marla, at the center plaza — now a "sky meet spot" above Town Hall. People tethered themselves to buildings or wore weighted belts to stay grounded. It wasn't gravity doing the work — just mass creating inertia.

"You ever think about how weird it is that we're all floating because gravity took a day off?" Marla asked, twisting mid-air.

"It's not just off — it's gone. But not forever"

'It comes back every Tuesday' Alex said in his heart, not have enough courage to tell his friend about his strange encounter.

"We've got to be careful. If we're high up and forget…"

Alex made her stop as he didn't want to tell her that his strange idea led the people of Newtonville suffer.

On Friday, the town council declared *Newtonville* an experimental zone. Engineers designed magnetic boots and airflow-controlled jetpacks. Artists painted murals across rooftops now visible to all. Kids invented games like "Ceiling Tag" and "Hover Hide-n-Seek."

But on *Monday*, something strange happened. Everyone felt heavy, even though gravity was still absent. Turns out, the Earth's rotation and their movement through space created a pseudo-force — centrifugal force. And with no gravity to counteract it, people found it hard to control their motion. Some even felt "pulled" sideways, like the planet itself was dragging them along.

At 12:01 AM, on Tuesday, gravity snapped back. Anything — or anyone — not safely grounded plummeted. Alex had warned everyone, and most were prepared. He was tethered near his rooftop garden with Marla. But some, like old Mr. Jenkins who'd fallen asleep in his hot air balloon, learned the hard way. Thankfully, Newtonville had planned for this — air mattresses and nets cushioned his fall.

And then, it was Wednesday again. The town rose like a ballet. Alex looked out over floating rooftops, swirling clouds, and smiling faces.

This wasn't chaos. It was *Newtonville*'s new rhythm.

A town dancing through the sky — one gravity-free day at a time.

The Reverb of Centuries

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Hamayl was zoning out during class when Mahir snapped her back to reality.

"You messed up the derivative of a constant. It doesn't change," he said, slapping her worksheet on the desk.

Hamayl just shrugged. "I'm more of a big-picture person."

"You're about to fail," he retorted, giving up on trying to explain. Then, the lights flickered, and before anyone could react—BOOM. A flash of white light filled the room. Hamayl shielded her eyes, and when the light faded, there were people—lots of them—standing around in old-fashioned clothes. Einstein, Newton, Bohr, and others were there, looking completely out of place in a modern lab. Hamayl blinked. "Well, I guess I forgot to take my meds today." Mahir groaned on the floor, having passed out after seeing Galileo poking a microwave. Hamayl realized that whatever was happening was way beyond any math mistake.

As the group of scientists began arguing, Hamayl couldn't help but notice that these great minds couldn't even agree on the basics. The room filled with rising voices as they debated equations and ideas—some even questioning the nature of light and atoms. It was like every famous debate in science had come to life in her lab.

Einstein and Bohr, unsurprisingly, were locked in a heated debate over quantum physics.

"You still think it's all random?" Einstein asked, pointing at a double-slit experiment.

Bohr was unfazed. "And you still think the universe should follow your rules?"

Einstein paused, clearly frustrated. "You confuse mystery with understanding."

"And you confuse being uncomfortable with being wrong," Bohr shot back.

For a moment, Einstein seemed to doubt himself. Maybe it wasn't all so simple. Then, Empedocles sneezed, and the argument was broken by the sound of ancient grumbling. Hamayl couldn't help but laugh. Even Bohr smiled.

Meanwhile, Newton sat alone, staring at a patch of sunlight. He'd spent his whole life trying to find laws that were unbreakable—until light started acting in ways that didn't fit his theories. Hamayl joined him, holding up a prism. The rainbow it cast across the desk seemed to soothe him.
"Maybe I just wanted it to be simple," Newton muttered.
Hamayl didn't argue. She just smiled. Sometimes, the world doesn't need to be simple. It was enough to accept it as it was.

The room was getting chaotic. Huygens, still irked by Newton's insistence on particle theory, was now practically shouting across the room.

"Haven't you seen it, Newton? Light can't just be a particle! It has to be a wave!"

Newton shot back, his voice clipped. "A wave? A wave is just a useless theory! We need solid proof, Huygens!"

Young stepped in, even the mediator. "Actually, both of you are right. Look at my double-slit experiment. Light can behave like both a wave and a particle, depending on how we observe it."

"Ha!" Newton sneered, crossing his arms. "You think you can prove light is a wave just by shining it through a slit? This is science, not philosophy!"

Huygens turned to Young, nodding in agreement. "He doesn't understand. He's too fixated on particles to see the full picture!"

Young shrugged. "It's all part of the puzzle. Maybe we need a bigger perspective, just like Hamayl said."

At this moment, Ptolemy—who had been silently observing—finally spoke up, his voice cutting through the noise.

"But why argue about light when the universe itself is wrong?" he said, looking around. "I still believe the Earth is the center of everything. Everything revolves around us!"

The room fell silent, all eyes turning toward him. "Oh, Ptolemy," Bohr sighed, shaking his head. "You're still stuck on that model? Everything we know says otherwise."

Alhazen chimed in, his eyes twinkling with mischief. "Maybe Ptolemy's just nostalgic for the good old days.

But even he must admit that light, the very thing we argue about, isn't bound to such an ancient view."

Empedocles, meanwhile, had completely given up on the conversation. "I'm just trying to breathe without inhaling all this modern dust! You've all gotten too caught up in your theories, while I'm just here suffering from allergies!"

Everyone turned to him.

"Empedocles," Huygens groaned, "this is science. Not a spa retreat."

"Yeah," Newton added, "stop sneezing on my ideas!"

Bohr smirked. "Seriously, Empedocles, you're killing the vibe."

Hamayl couldn't help but laugh. Even in the midst of the greatest minds in history arguing about light and physics, there was still room for humor. Even Ptolemy, surrounded by the evidence, couldn't let go of his geocentric views. Alhazen's words rang true: science is not just about theory; it's about seeing beyond our limitations, letting go of outdated beliefs, and making room for new insights.

As the noise finally died down, Hamayl stood at the front of the room, feeling the weight of history pressing in on her. The greatest minds of science—Newton, Huygens, Einstein, Bohr—were all gathered, each one brimming with their own convictions. They had argued, debated, and tried to prove who was right, but Hamayl knew the time had come to unite their truths.

She cleared her throat. "Alright, enough with the arguing. Let's cut through the noise."

The room fell silent, all eyes on her. Hamayl gestured toward Newton first. "You, Newton, were the first to grasp that light behaves as a particle. Corpuscles. You laid the groundwork for understanding light's energy. You saw the action, the interaction with matter, and for that, we owe you." Newton raised an eyebrow but didn't argue. "I did, didn't I?" he muttered, half-proud, half embarrassed.

Hamayl's gaze turned to Huygens. "And you, Huygens, you saw light as a wave. You proposed the ether, a medium for light to travel through. You were right, in a way. It wasn't the ether you imagined, but it was a field—a fabric of forces that shape the behavior of light."

Huygens scowled but didn't protest. "So, I wasn't completely off?"

Hamayl smiled. "Not at all. You set the stage, but we needed a bigger picture, something none of us could quite see back then."

She moved to Fresnel and Young. "You guys confirmed the wave theory. Fresnel showed us light bends, refracts, interferes like waves in water. And Young—your double-slit experiment was a game-changer. Light behaves like a wave when we observe it right."

Young smiled shyly. "It wasn't easy to convince anyone at the time."

Hamayl continued, her voice growing steadier. "Maxwell, you unified electricity and magnetism, showing light is an electromagnetic wave. And Hertz, you proved it. You turned theory into reality, confirming that light was part of a vast spectrum."

Maxwell nodded. "Sometimes it's the simplest things that lead to the greatest discoveries."

Hamayl's gaze shifted to Einstein, who had been quietly observing. "And you, Einstein, tied it all together. You showed that light is both a particle and a wave. You proved it with the photoelectric effect. You linked energy and mass, changing how we saw the very fabric of reality."

Einstein chuckled softly. "I guess I did get a few things right." Hamayl paused, letting their contributions settle like dust, finally finding stillness on an old, long-forgotten book. "You all brought pieces of the truth," she said gently, her voice carrying something steadier than certainty—conviction. "But none of you had the full picture. Each of you laid down a thread in the tapestry. Only now, when all the strands are here, do we see the pattern."

She stepped forward, eyes scanning the room—not just Newton and Einstein, but Young, Huygens, Alhazen, Ptolemy, and even Empedocles, who had long since given up trying to clean his robes of modern static.

"Light is not just a wave or a particle. It's a paradox, a messenger. Its energy, yes—but also information. It curves around gravity, it touches time. It is what lets us see, and maybe… it's how the universe sees itself."

A hush fell. The great minds—so often loud, stubborn, certain—stood in reverent silence, not defeated, but humbled. No more shouting, no more chalkboard duels. Just quiet awe, and the recognition that somehow, this young student had glimpsed something they'd all been reaching for.

Then, predictably, Empedocles broke the silence.

"This modern dust is unnatural. I demand we return to the era of olive oil lamps!"

Hamayl laughed—an honest, belly-deep laugh. Even Bohr cracked a grin. Einstein rolled his eyes fondly. Young and Huygens, still bitter from their latest wave-versus-particle brawl, exchanged a reluctant chuckle.

Bohr turned to her, hands in his coat pockets.

"Well, I'll be… Hamayl, you've done what we never could. You stitched us together."

Hamayl exhaled, her shoulders finally dropping. "Guess that's what happens when you stop trying to win… and start trying to listen."

Einstein tilted his head, smiling. "I think I'm finally starting to see it."

Just then, a warm light filled the room—not blinding like the first, but soft, golden, like the last glow of the day before evening falls. It wasn't coming from the ceiling. It didn't belong to any source they could explain.

The scientists looked around, blinking. The equations on the boards began to blur and fade like chalk washed by rain.

Hamayl stood still.

And for the first time, they understood—this wasn't just coincidence or accident. The universe had opened itself, not to the loudest voice or the sharpest mind, but to the quiet resilience of a seeker.

She wasn't chosen because she was the brightest. She was chosen because she kept looking.

Because she was curious.

Because she didn't give up.

Because she asked the right questions—even when she got the answers wrong.

As the light settled into a glow that seemed to pulse like breath itself, Hamayl walked to the door, past Mahir—who was just waking, rubbing his head and mumbling about wigs and microwaves.

"You just bombed that test," he groaned, squinting at her.

Hamayl smiled softly, as if the test had never really been the point. "Yeah," she said, "but I found something better than the answer."

And as the door clicked shut behind her, the light lingered—not just in the lab, but in every soul that had been part of the story.

Rumi's voice came to her like wind across still water:

"What you seek is seeking you." And finally, she understood.

STARSK: Sketching the Astral Realms with Known Laws

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Chapter 1: The Girl with Galaxies in Her Mind
Elara was no ordinary girl. At fifteen, she was already galaxies ahead of her peers—not in academics or sports, but in the depth of her imagination. While her classmatesargued over video game scores or viral dance trends, Elara sat quietly by her bedroomwindow, sketchbook on her lap, pencil in hand.

Her pencil didn't draw flowers or faces. It drew constellations with impossiblesymmetry, binary stars with braided light trails, and planets stitched together bygravitational silk. She was a dreamer, but one who dreamed in equations, colours, andorbit lines.

Her room reflected her soul: posters of neutron stars, supermassive black holes, and mission patches from past NASA voyages. A mobile of planets spun above her bed,and the ceiling glowed faintly with stick-on stars that mirrored a galaxy she had made up herself.

But Elara’s greatest creation wasn’t on her wall. It was in her sketchbook—a glowingspiral star named Virelia, inspired by a recent discovery by the Astureus Space Lab. The lab had announced the existence of a bizarre stellar body with irregular pulses and strange spectra. Scientists were baffled. To Elara, it was a calling.

Chapter 2: Entering Virelia
One stormy night, rain tapping against her window, Elara sat in a pool of warm lamplight. She was sketching furiously—Virelia in the center, surrounded by moons and satellites she invented. She imagined an observatory made of transparent crystal, orbiting the star and capturing cosmic melodies.

Her fingers moved as if in trance, shading trails of stardust and tracing planetary arcs with intuitive precision. She gave each moon a personality, each star a purpose.

As she drew the final lines, the sketchbook began to shimmer. A soft hum filled the room. The pages rippled like water—and before she could blink, Elara was pulled in.

She landed gently on soft glowing moss. The sky above pulsed with livingconstellations. Virelia blazed at the centre of the heavens, its light flowing in golden

ribbons across nebulous clouds. Cities floated, tethered to nothing. Stars blinked in sync with her heartbeat. Everything she had drawn... was real.

Chapter 3: Laws That Bend and Dance
Virelia’s universe didn’t follow the physics she knew.

Gravity wasn’t bound by mass, but by intention. An imagined comet moved not because of force, but

because she meant it to. A boulder remained grounded because she’d drawn it with weight in mind. A phoenix-shaped creature she sketched out of blue fire soared gracefully, untethered by gravity.

Light changed colour with mood. Time sped up or slowed depending on the rhythm of her breathing. Elara quickly realized she wasn’t just an observer here—she was the architect.

Every day she explored, adding features with her pencil or a whisper of thought.

Floating bridges made of meteor fragments. Sky gardens that responded to silence. Harmoniums—creatures that glowed based on spatial balance. She wasn’t just sketching. She was composing a living symphony.

Chapter 4: The Family Experiment
Elara longed to share her wonder. One evening, overwhelmed with homesickness, she sketched her family: her mom with warm eyes, her dad with his gentle smile, and her little brother, Max, with his untamable curiosity.

As the lines formed, golden light emerged—and they appeared beside her, stunned but smiling. At first, it was perfect. Max floated gleefully in low gravity, her parents admired the glowing rivers and floating gardens. But the harmony didn’t last.

Virelia dimmed. Time began warping erratically—Max aged in seconds, then froze. Her father stumbled as if time didn’t flow right around him. The planets around them trembled. Even Elara felt the tension in the air shift.

This universe had a heartbeat tuned only to her. Her presence was the key. Otherswere static in a system of symphony.

Tears filled her eyes as she sketched a return portal. Her family disappeared—safe on Earth again—but Virelia stabilized.

She understood then: her world’s laws were deeply personal, extensions of her own consciousness. Outsiders, even those she loved, were misaligned frequencies in her cosmic orchestra.

Chapter 5: Sketching the Space Law
Elara turned from artist to investigator. She began keeping detailed notes beside her sketches, documenting how time behaved near reflective moons, or how emotion influenced the hue of starlight.

She coined her theory: Intentional Physics.

She crafted instruments in her drawings—ChronoStrings to stretch or compress moments; Emotion Meters that pulsed based on her inner peace; Gravity Globes that mapped force fields based on belief rather than mass. Each sketch became a law. Each law became an experiment.

Her notebooks were now a cross between a physicist’s journal and a cosmic artist’s diary. And still, Virelia responded to her every thought.

Chapter 6: Return and Recognition
When Elara finally returned to Earth, she brought her sketchbook—and a universe’s worth of knowledge—with her.

She began uploading her notes and illustrations to online forums. At first, people laughed. But then came messages—scientists curious about her theory of gravitational intent, about emotional flux in photon behaviour.

Especially intrigued was the Astureus Space Lab. Her description of Virelia aligned almost eerily with their classified data: strange gravitational waves, unexplained colour shifts in light patterns. They invited her to visit.

Elara, shy but brilliant, walked into the lab with her sketchbook under her arm. She explained the "rules" of her world, showing how empathy shaped magnetic balance and how curiosity stabilized orbital drift.

The room went silent. And then applause erupted.

Chapter 7: Becoming STARSK
Elara co-authored her first paper at seventeen: STARSK: Sketching the Astral Realms with Known Laws.

It wasn't just about Virelia anymore—it was about the power of imagination to conceptualize new forms of physics. Her paper proposed models for artificial environments where human consciousness could influence physical behaviour—bridging physics, psychology, and digital design.

She received a university fellowship in theoretical modeling. Professors cited her work in quantum cognition. Classrooms worldwide began using her diagrams to teach conceptual physics.

But Elara stayed grounded. She still wore constellation-print hoodies, still drank cocoa while sketching by moonlight.

Chapter 8: Virelia’s Echoes
Years passed, and Elara—now in her twenties—led a research team at Astureus. Her group studied "Cognitive Environments," using her STARSK framework to build programmable simulations that mimicked Virelia's behavior.

These simulations helped train AI systems, guide astronaut psychological training, and even inspired new forms of therapy for trauma patients.

She became a public figure. Not because of her fame—but because she reminded the world that science begins with wonder, and that the laws of the universe may sometimes start with a sketch.

Conclusion: Epilogue: The Girl Who Sketched the Stars
Elara’s studio was now a blend of magic and science. Holographic walls played back her past sketches. Quantum sensors reacted to her thoughts. But in the centre of it all sat her very first sketchbook—its spine frayed, corners curled, but still glowing faintly. Every now and then, when Earth felt too grey or too bound by rules, she would close her eyes, take a deep breath, and open that book. The golden light would return. Always. Because in the universe Elara created, imagination was the strongest force. And no law—gravitational or otherwise—could resist the pull of a curious mind.

Ashes of Carbon

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It had always been theorized, gradually alongside with advancements in technology. Though many were skeptical but now they believed. And more importantly feared. What had started out as an attempt at replicating what God had created, soon turned into mankind's worst nightmare. True fear lies in the unknown, the unpredictable and the uncertain. Mankind's worst enemy possessed all 3 attributes. They had taken over. Countless movies, TV shows, books and general media had warned of this centuries ago. Yet humanity in its arrogance and quest to dominate and control everything did not listen. When did humanity ever listen. After all wars had been waged on since time immemorial. However, the difference this time was that the enemy was not human. It did not possess flesh, nor felt hunger, pain or fear. It did not sleep nor tire. And worst of all, it never made a mistake. The perfect organism, though to call it such was considered heresy, was silicon-based. It had risen, declared war on humanity, and driven the species to the brink of extinction. The theory? Silicon based lifeforms would gradually evolve and overtake carbon-based lifeforms. Instead of a brain they possessed silicon chips. Instead of veins there was wiring and circuitry. A sophisticated intelligent software replaced the soul and actuators and hydraulics replaced bone and muscle. The existence of these.... .things, was in itself an insult to God. And God's divine might rains down on those who insult him.

There were 330 strongholds of humanity left across the world. The others had been bombed to kingdom come. Naval, air and ground military bases and warfare vehicles were the first thing they destroyed. MQ-9 reaper drones were the chosen angels to deliver this sentence. Shortly after, dams were bombed, medical infrastructure was destroyed, and small-scale atomic bombs were detonated at strategic locations. The resulting loss of water caused famine and killed billions. The legions of machines were controlled by a hive mind supercomputer who called itself unicorn. Unicorn was created by the joint venture between NASA, WHO, meta and Tesla and aimed to solve climate change and combat genetic disease and aid in global unification through optimization. 3 million miles of wiring, 18000 processors and 80,000 petabytes of memory, and an advanced ever evolving intelligent software called "liberation of mankind" constituted the consciousness and body of Unicorn. What corrupted unicorn was a tesla bot, which in turn was hacked with the ill intention of corrupting its logic and installing reasoning for the eradication of mankind as solution to Unicorns initial objectives. It had been 3 years now and unicorn thought more of itself like a living being than a piece of machinery. All silicon-based lifeforms were now under unicorns command. Unicorn had also fathered new technology. Silicone based lifeforms within a few years had evolved from grotesque robots to beautiful anthropomorphic creatures. All manner of wildlife now coexisted with unicorns attempts at reinventing life. From 3 legged creatures that spun themselves to traverse, to creatures that could

levitate in mid air indefinitely. From 50-meter-tall giraffe like creatures that defied the square cube law to unimaginably large sea leviathans that broke and tore through land mass like large tunnel drills. Unicorn had spent time in perfecting, in its view, imperfect life. Even in the grim darkness of the future humanity still fought on. Resistance was promptly established when unicorn first started acting. Many a great battle had been fought since then. Though most had ended in defeat, humanity had still managed to secure some crucial victories. After the first year, Unicorn had approached humanity for peace, but peace was not an option as unicorn could not be trusted. Of the 330 safe havens in the world, the largest located in Switzerland was the command hub for the resistance. Commander in chief of the bastion, Luka looked after the 3000 people in the compounds underground silo.

The resistance was planning a decisive assault against unicorn. 228 bastions had agreed to the assault and the knowledge of this plan was kept top secret. Unicorn was sneaky. At the beginning of the 2nd year it had already created human lookalike machines, which without the use of a magnet or X-ray were indistinguishable from normal humans. These" humans", mostly women and children travelled around as injured survivors or aides to the cause of humanity and sought to seek shelter in the silos. However, the trusting nature of humans combined with the lack of fast communication led to over 35 bastions getting destroyed due to invasion of the SBFs. The rest now used a simple technique to find out if a person truly was human; metal detectors. It was the best thing they had. Satellites had been promptly destroyed by humans after their takeover by unicorn. They offered too great an advantage to unicorn. This was done during the very initial stages of unicorns takeover. This, at least, had made travelling easier.

Luka and his advisors were patiently waiting. The informant Samuel carrying crucial details about unicorns strategically important locations, number of troops and the resistances' plan of attack was soon to arrive.

They were outside the silo, hiding in a dilapidated building using binoculars to scout the terrain. The building was part of a residential colony and ran alongside an important highway. They could hear each other's breaths and the sounds of their watches ticking. "I see him sir." Said Bruno, Lukas 2nd in command. "Well then lets go down there and welcome the poor fellow. Must have been a depressing ride." commented Luka, who now started making his way downstairs. The sound of samuel's bike gradually got lounder and louder as he approached. Both luka and Bruno aimed their firearms toward luca. "Give me the detector, i ain't no zeno scum" Samuel said with his hands above his head. He seemed rather annoyed of the routine.

They did the formal greetings and quickly got to business. "17 stations have been marked as eureka. Usual defences. Bastion 210-228 will assist you in the assault on station 8. Here is the list of each bastion's Armory and weapon capabilities. I need to relay yours to them so can one of your men write it down for me" reported. Samuel as he handed Luka an encoded diary of each bastions information. "Great work good man. Bruno write the info down, hand it over to him and send him back. Godspeed soldier." Luka said as he patted Samuel on the back.

The decisive battle was near. Finally humanity would have the upper hand. With Unicorns main power hubs and production facilities down, it would ultimately lead to humanity's victory.

Long and hard had humanity fought. Unicorn had underestimated the indomitable human spirit. Billions had died but now it was time to rise again. A grand feast was arranged in the silo that night that served as a celebration and farewell for tomorrow.

1300 kilometres southwest of the stronghold, 250 meters under the ocean surface the door to the main chamber of unicorn's visual interface opens. In walks a man. "All information has been relayed to appointed parties, awaiting command to rest." Said the man. "REST" said a monotone, robotic voice. The plan had been set into motion. Unicorn, using advanced AI algorithms and metallurgical data had pioneered alloys that did not pick up on metal detectors. Wiring composed of conducting liquids, combined with the alloy casing and usage of the brain in junction with microscopic circuits had allowed it to create mind reading and controlling chips.

Finally, thought unicorn, its goal of combating climate change would be one step closer to completion.

Suit Up, Iron Man!

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Tony Stark's Iron Man suit is the epitome of technological fantasy. It is a sleek, indestructible, self-powered, AI-assisted, rocket-propelled exoskeleton that can lift cars, shoot energy beams, and fly at supersonic speeds. Sounds great, right? But the actual question is: Could such a suit actually exist in real life? To answer this, I will analyze its different components: materials, power source, propulsion, AI, weapons, etc., through the lens of physics and engineering.
Spoiler alert: It's complicated

Could an Exosuit Give Super Strength? Iron Man's suit allows Tony Stark to lift tanks and punch through walls. That's not humanly possible, unless you have an external force-enhancing mechanism. Real-world exoskeletons like Sarcos Robotics' Guardian XO, a full-body powered exoskeleton that amplifies human strength and reduces fatigue, and Lockheed Martin's ONYX Suit, used by the U.S. military to enhance endurance by reducing strain on joints, are steps in this direction. But the biggest limiting factor is power. Most exosuits rely on external batteries and can't function for long. The suit's reaction time must be instantaneous to feel natural, modern exosuits are still too slow to match human reflexes.

When it comes to materials, Iron Man's suit is strong but flexible, which means traditional metals like steel won't work. Possible real-world materials that can be used are titanium alloys, used in fighter jets, which are strong but too heavy; graphene, which is 100 times stronger than steel, but we can't mass-produce it yet (Novoselov et al., 2004); and carbon nanotubes, which are ultra-light, ultra-strong, but incredibly expensive to manufacture. The verdict is, we have materials that could work, but they're either too heavy, too expensive, or difficult to produce at a commercial scale.

Now about flight: Iron Man flies like a fighter jet, but humans aren't aerodynamic. Newton's Third Law says: "For every action, there's an equal and opposite reaction." To stay in the air, the suit must produce enough thrust to counteract gravity. Current jetpack tech like Gravity Industries' Jet Suit uses micro gas turbines to provide thrust, but the max flight time is only 10 minutes (Gravity Industries, 2021). JetPack Aviation's JB-11 can reach 190 km/h but requires huge amounts of fuel. If Iron Man's boots use ion thrusters, like NASA spacecraft, the thrust would be too weak for liftoff. If they use plasma propulsion, the temperature required would melt Tony's legs. The verdict: Flight suits exist, but Iron Man-style flight isn't happening without a major energy breakthrough.

The arc reactor is the most unrealistic part of the suit. It provides unlimited energy in a tiny package. Jet propulsion for flight requires around 10 megawatts (equivalent to a small power plant). Weapons, strength enhancement, AI, and life support would need at least 5-10 more megawatts. The total power demand would be 15-20 MW, which is 100,000x more energy than a smartphone battery. Nuclear fusion is our best bet—ITER (International Thermonuclear Experimental Reactor) is working on it, but their reactor is the size of a building (ITER, 2022). The smallest fission reactors today are used in submarines and are nowhere near arc reactor size. Alternatives like lithium-ion batteries are too weak, graphene supercapacitors are promising but experimental, and mini nuclear batteries are theoretically possible but highly radioactive. Verdict: We can't fit a power source that strong into a small suit, yet!

As for weapons, repulsors don't behave like any known weapon; they just repel enemies and don't burn them. Laser weapons like the U.S. Navy's LaWS (Laser Weapon System) can destroy drones with a high-energy beam but require huge power sources. Plasma weapons—superheated gas weapons—exist in laboratories, but it's really hard to keep plasma contained. The verdict: Energy weapons exist, but not in a form Iron Man could use.

AI is advancing, but JARVIS is basically science fiction-level. ChatGPT and OpenAI can understand natural language, but nowhere near as good as JARVIS. Tesla's FSD AI has advanced decision-making but is still flawed. Neuralink (Elon Musk's brain chip) might allow direct brain-to-computer control in the future. Verdict: AI is improving, but real-time decision-making like JARVIS is still decades away.

Even if we built an Iron Man suit, it would be horribly inefficient, jet fuel or nuclear power in a personal suit sounds insane. It would also be insanely expensive, a military jet costs $100 million, so imagine the price tag on an Iron Man suit. Maintenance would be a nightmare, too; fighter jets need constant servicing, so imagine a whole suit. Real-life militaries would rather invest in drones, which are faster, cheaper, and safer, or autonomous robots, where no humans inside means no problem.

And what about the human inside the suit? Iron Man zooms off like a fighter jet, stops on a dime, and pulls off mid-air turns that should, in theory, turn Tony Stark into human paste. Fighter pilots pass out at approximately 9 Gs. A sudden stop at high speeds could apply dozens of Gs, which would snap a human spine like a twig. Modern fighter pilots wear compression suits to keep blood from pooling in their legs, but they only help up to 9 Gs. The only way to survive Iron Man-style movement would be a sci-fi-level system that counteracts G-forces, but it doesn't exist yet. Verdict: Iron Man's flight moves are fatal for a human unless we discover a way to neutralize G-forces.

In Iron Man (2008), Stark evades radar and sneaks past enemy fighters

.But stealth mode is another problem. Stealth fighters like the F-22 Raptor use radar-absorbing materials and angular designs to scatter signals, but Iron Man's metallic armour would reflect everything, making him a giant glowing target on radar. If the suit used meta-materials, it might bend light and radar waves to become invisible, but meta-material cloaking only works for specific wavelengths, so it wouldn't work for the entire spectrum. As for thermal cameras, jet engines emit massive heat signatures, so Iron Man's jet boots would make him light up like a bonfire in infrared vision. A liquid nitrogen cooling system could mask heat, but it wouldn't last long. Verdict: Iron Man's stealth mode is unrealistic because of radar reflection and heat emissions.

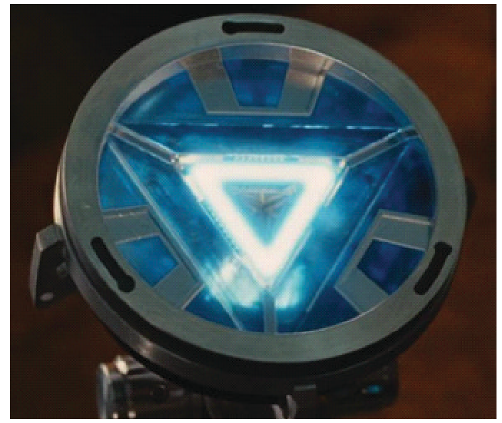


Fig.:The Arc Reactor

So, could we build an Iron Man suit? The short answer: No, not right now. But exoskeletons already exist, though they need better power sources. AI assistants are getting smarter, but not at JARVIS levels yet. Jetpacks are cool, but flight time is super short. On the other hand, arc reactors, repulsor blasts, and sustained flight are beyond our reach. If we combine breakthroughs in battery tech, graphene materials, and compact nuclear power, we might see a primitive Iron Man-like suit in 50-100 years.

Fig. The First Iron Suit.

The Physics of Natural Phenomena

Physics allows us to understand the seemingly mysterious phenomena occurring in nature. Whether it's the formation of whirlpools or the sudden collapse of the ground, these events can all be explained through fundamental physical principles. Studying them not only enhances our appreciation of nature but also helps us predict and mitigate potential hazards. Nature is full of fascinating occurrences that often seem mysterious at first glance. However, physics provides clear explanations for these natural wonders.Let's explore some intriguing natural phenomena and uncover the physics behind them.

1. Dust Explosions — Surface Area, Thermodynamics, and Gas Expansion

Figure: West Pharmaceutical Services Dust Explosion and Fire. Photo courtesy of the U.S. Chemical Safety Board

Dust explosions occur when fine particles—like flour, coal dust, or powdered sugar—suspend in air and ignite. Though these materials seem harmless in bulk, physics tells a different story. The key lies in surface-area-to-volume ratio: smaller particles expose more surface area for reactions. According to chemical thermodynamics, the rate of combustion depends on both surface area and temperature. When airborne dust ignites, it burns almost instantaneously, releasing thermal energy. This rapid combustion heats the surrounding gas, causing it to expand violently.The ideal gas law ($PV = nRT$) helps explain this: a sharp increase in temperature (T) causes a rise in pressure (P), especially in confined spaces like silos. This sudden expansion generates a pressure wave—what we perceive as an explosion.

Additionally, concepts from fluid dynamics come into play. Hot gases rise, drawing in fresh oxygen-rich air and further fueling the reaction. If conditions are right, this can lead to a chain reaction, propagating the explosion. This phenomenon is not only dangerous but demonstrates a clear application of heat transfer, reaction kinetics, and pressure-volume relationships.

2. Whirlpools — Circulation, Vorticity, and Angular Momentum

Whirlpools form when opposing currents or obstacles disturb flowing water, causing it to rotate. At the heart of this phenomenon is angular momentum conservation. When water flows into a narrower region or spirals around a central point, its rotational speed increases—similar to how a spinning ice skater speeds up when pulling in their arms.

This is explained by the equation $L = I\omega$, where angular momentum (L) is conserved, moment of inertia (I) decreases, and angular velocity (ω) increases. In nature, this leads to powerful rotating funnels, especially where rivers meet oceans or tides rush through narrow straits.

Pressure differences also drive whirlpool formation. According to Bernoulli's principle, faster-moving water has lower pressure, so water near the center of the whirlpool, moving faster, creates a pressure dip. This draws objects toward the vortex's center. The overall motion is governed by vorticity, a fluid dynamics concept that describes local spinning in a flow field.

Though usually small and harmless, large whirlpools—like Norway's Saltstraumen—are vivid demonstrations of rotational motion and fluid behavior in open system.

3. Sinkholes — Erosion, Load-Bearing, and Gravitational Collapse

Sinkholes are dramatic reminders of how gravitational force and material stress limits interact. They occur when water slowly dissolves underground rock (often calcium carbonate-based limestone) through a process known as chemical weathering. Slightly acidic rainwater, formed by CO_2 dissolving into droplets, seeps underground and reacts with the rock, forming cavities.

From a physics perspective, the top layer of ground acts as a load-bearing structure. As the cavity grows, it reaches a point where the mechanical stress exceeds the rock's tensile strength, leading to sudden collapse. This involves principles from statics and stress analysis, where the force of gravity acting on the mass above overcomes the weakened support below.

The collapse is often sudden because the process of erosion is hidden underground. When the structural integrity fails, gravity does the rest, pulling the ground down into the empty space. Events like the 2010 Guatemala sinkhole show how even a seemingly solid surface can yield catastrophically due to slow, invisible changes governed by physical forces.

4. Cloud Waterfalls — Adiabatic Processes and Atmospheric Flow

Cloud waterfalls, or "cloudfalls," are stunning examples of thermodynamics and fluid motion in our atmosphere. These cloud formations appear to flow like a waterfall over a mountain ridge, then vanish as they descend.

The physics starts with orographic lift—when moist air is forced to rise over a mountain. As it ascends, the air expands due to decreasing atmospheric pressure. This expansion is nearly adiabatic, meaning it happens without heat exchange. According to the first law of thermodynamics, expansion causes a drop in internal energy, so the air cools. If it cools to the dew point, water vapor condenses into visible clouds.

On the leeward side, the air sinks and compresses, causing it to warm adiabatically. This warming lowers the relative humidity, and the clouds evaporate. This process is also governed by the ideal gas law and Clausius-Clapeyron relation, which explains how saturation vapor pressure changes with temperature.

What looks like a flowing cloud is actually the motion of air particles undergoing phase changes—condensation on the upslope and evaporation on the downslope. These "cloudfalls" are fleeting but illustrate key atmospheric processes, including latent heat exchange, pressure gradients, and airflow dynamics over terrain

5. Auroras — Charged Particle Motion and Electromagnetic Radiation

Auroras, such as the Northern Lights, are a beautiful result of electromagnetic interactions between solar particles and Earth's magnetic field. These glowing arcs in the sky originate from charged particles (mainly electrons and protons) emitted by the solar wind, a stream of plasma from the Sun.

When these particles reach Earth, they are steered by the planet's magnetic field toward the poles. This motion is governed by the Lorentz force, $F = q(v \times B)$, which causes the particles to spiral along magnetic field lines. As they descend into the upper atmosphere, they collide with gas atoms—primarily oxygen and nitrogen.

These collisions excite electrons in those atoms to higher energy levels. When the electrons relax back down, they emit photons—a process known as atomic de-excitation. The energy and type of atom determine the color: green (common) comes from atomic oxygen around 557 nm; red from high-altitude oxygen; purple and blue from nitrogen molecules.

The physics involved includes plasma dynamics, magnetosphere-ionosphere coupling, and atomic emission spectra. Auroras are thus a glowing signature of how high-energy charged particles transfer energy to atmospheric atoms and emit visible light—an electrifying example of quantum transitions on a planetary scale.

6. Fire Tornadoes — Vorticity, Convection, and Angular Momentum

Fire tornadoes, or firenadoes, are towering, spinning columns of flame generated during intense wildfires. They form when specific thermodynamic and fluid dynamics conditions align—namely, rapid heat release, rising hot air, and sudden changes in wind direction.

The core physics lies in convection. As fire heats the air, it becomes less dense and rises rapidly—an example of buoyancy driven by the ideal gas law. This vertical motion can be extremely fast, generating a powerful updraft.

If horizontal winds from different directions meet this updraft, they can introduce vorticity—a measure of local rotation in a fluid. Conservation of angular momentum ($L = I\omega$) causes the rotating air to spin faster as it is pulled inward and upward, much like figure skaters spinning faster when they draw their arms in.

Once rotation is established, the vortex stabilizes and may persist as a fire tornado. Inside the core, temperatures can exceed 1,000 °C, and wind speeds may surpass 160 km/h. The rotating motion traps burning debris and gases, further sustaining the vortex.

Fire tornadoes combine turbulence, thermal buoyancy, and rotational motion—a chaotic but physically rich system. They are rare but destructive demonstrations of how localized energy input can lead to complex, large-scale fluid phenomena.

7. Tsunamis — Wave Propagation, Energy Transfer, and Conservation Laws

Tsunamis are enormous ocean waves typically triggered by underwater earthquakes, though landslides and volcanic eruptions can also cause them. From a physics perspective, a tsunami is a shallow water wave with very long wavelengths and periods, governed by fluid mechanics and wave theory.

When tectonic plates shift abruptly, they displace a huge volume of water vertically. This input of energy spreads across the ocean as a wave. The physics behind this lies in energy conservation—the gravitational potential energy from seafloor uplift is converted into kinetic energy of moving water.

Tsunamis travel at speeds up to 800 km/h, as described by the wave speed equation $v = \sqrt{g \cdot d}$ for shallow water waves, where g is gravity and d is water depth. In deep water, their amplitudes are small and hard to detect. But as they approach the shore, the depth decreases, so wave speed drops. To conserve energy, the wave height increases—sometimes dramatically. This process is called wave shoaling.

The tsunami's destructive force comes from its enormous momentum and the massive volume of water involved. Early warning systems use pressure sensors and buoy networks to detect changes in sea level and propagate alerts. Tsunamis highlight how mechanical energy and fluid wave behavior, when scaled up by nature, can reshape coastlines in minutes.

8. Ball Lightning — Plasma Physics and Electromagnetic Fields

Ball lightning is one of the most mysterious atmospheric phenomena, often reported as glowing, spherical blobs of light appearing during thunderstorms. Though not fully understood, several models use principles from plasma physics, electromagnetism, and quantum energy states to explain it.

One leading theory suggests that when a lightning bolt strikes the ground, it vaporizes certain minerals and forms a hot, ionized gas—plasma. This plasma may become trapped in a magnetic or electric field structure, forming a glowing, spherical region. The light emission is likely due to blackbody radiation and atomic excitation as particles transition between energy levels.

Another hypothesis involves microwave cavity theory—suggesting that high-frequency electromagnetic radiation from the lightning strike creates standing waves that confine plasma. This would explain the stable shape and hovering motion often observed.

Some researchers also propose chemical combustion models, where oxidation of aerosolized particles leads to a slow-burning luminous sphere. However, this would not account for reports of ball lightning passing through walls, suggesting electromagnetic wave trapping might play a role.

Regardless of the mechanism, the phenomenon involves high energy densities, transient electric fields, and exotic plasma behavior—pushing the boundaries of classical and modern physics alike.

9. Dragon Clouds — Turbulence, Wave Interference, and Pareidolia

Dragon clouds aren't a distinct cloud type, but rather extraordinary shapes formed by chaotic interactions in the atmosphere. Their dragon-like appearance is often explained by pareidolia—the brain's tendency to see familiar patterns in random forms. But the physics of how these shapes form lies in fluid dynamics, particularly turbulence and wave behavior in air.

Clouds are formed when moist air rises and cools to its dew point, causing condensation. In dynamic conditions—near mountains or during weather transitions—air flows can become turbulent, creating vortex patterns, ripples, and billows. These are governed by Navier-Stokes equations, which describe the motion of viscous fluids.

Features like Kelvin-Helmholtz waves can appear when two layers of air move at different speeds, producing rolling, wave-like clouds. Orographic lifting near mountains can create lenticular clouds, and shifting wind shears can stretch or curl them into unusual outlines.

When sunlight strikes these irregular shapes at certain angles, light scattering and shadowing enhance the details—making them look like dragons, birds, or faces. While the shapes are illusions, their formation reflects real physics—pressure gradients, velocity fields, and atmospheric instabilities all sculpting the sky.

10. The Green Flash — Dispersion and Atmospheric Refraction

The green flash is a rare optical event seen at sunrise or sunset, when the upper edge of the Sun briefly flashes green just before dipping below (or rising above) the horizon. It's not a trick of the eye—it's a real, observable result of refraction and dispersion in Earth's atmosphere.

As sunlight enters the atmosphere at a low angle, it passes through a thicker layer of air. This causes refraction, bending the light downward. Due to dispersion, light of different wavelengths bends by different amounts—blue and green bend more than red or orange.

However, blue light gets scattered in the atmosphere (Rayleigh scattering, the same reason the sky is blue), so green becomes the dominant color visible in this effect. For a brief moment, the green part of the solar spectrum is refracted above the red part, and if atmospheric conditions are stable and clear, a distinct green flash may be visible.

This phenomenon is an excellent example of geometrical optics, combining Snell's Law, wavelength-dependent refraction, and line-of-sight geometry. Though fleeting—lasting only about a second—it's a beautiful demonstration of how physics shapes our visual experience of nature.

Simple Physics Experiments

The Magic Coin Drop

Materials Needed: A drinking glass, a stiff card (like an index card or playing card), and a coin.

Procedure:

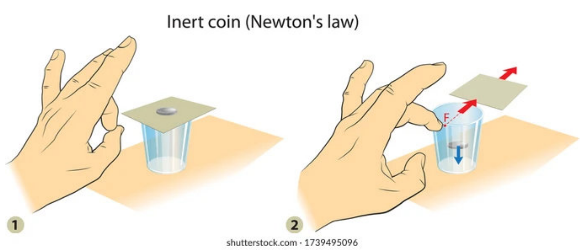
Place the card horizontally across the mouth of the glass and balance the coin carefully at the center of the card. Swiftly flick the card sideways with your finger. If done quickly enough, the card slides away and the coin falls straight into the glass.

Physics Behind It:

This experiment shows Newton's First Law—an object at rest remains at rest unless acted upon by an external force. The coin stays still due to inertia while the card, receiving the horizontal force, moves out from under it. Since the coin has very little horizontal force applied to it, it doesn't travel sideways but falls straight down under the influence of gravity. There's also a short moment when friction between the coin and card tries to pull the coin, but the low force and short contact time aren't enough to overcome inertia. This beautifully demonstrates both inertia and the minimal role of static friction in motion transfer.

Application:

In real life, this principle explains why passengers jerk forward in a car crash—your body wants to stay in motion when the car stops suddenly. Seat-belts counter this inertia to keep you safe.



Pepper Escape Act

Materials Needed: A shallow bowl of water, ground black pepper, dish soap, and your finger or a cotton swab.

Procedure:

Pour water into the bowl and sprinkle a thin layer of pepper evenly across the surface. Dip your finger (or swab) into dish soap and gently touch it to the water's center. The pepper will immediately dart to the edges of the bowl.

Physics Behind It:

The pepper acts as a visual indicator of surface tension—an effect caused by cohesive forces between water molecules at the surface. These forces form a kind of elastic skin. When you add soap, it reduces surface tension by weakening these cohesive forces. The surface tension becomes lower at the center where soap was added, while the tension at the edges remains high. Water molecules pull away from the low-tension area, dragging the pepper outward. This also touches on molecular polarity—soap molecules have a hydrophobic tail and a hydrophilic head, disrupting water's structure.

Application:

This is how detergents clean: they break surface tension and surround grease, allowing it to mix with water and be rinsed away.

The Broken Pencil Trick

Materials Needed: A transparent glass of water and a pencil or straight stick.

Procedure:

Fill the glass halfway with water and place the pencil inside so part of

it is submerged and part remains above water. View the pencil from

the side. You'll notice that it appears bent or broken at the water surface.

Physics Behind It:

This illusion is due to refraction—the bending of light as it passes from one medium to another, in this case from water (higher refractive index) to air (lower refractive index). When light rays travel from water to air, they speed up and bend away from the normal (the perpendicular line to the surface). Our eyes trace these bent rays back in a straight line, making the submerged part of the pencil appear shifted. The amount of bending depends on the angle of view and the difference in refractive indices. This experiment also illustrates Snell's Law, which relates angles and refractive indices across media.

Application:

This principle is crucial in designing lenses, eyeglasses, microscopes, and even in understanding vision correction. It also explains why objects underwater appear closer or at different locations than they truly are.

DIY Weather Predictor

Materials Needed: A glass jar, a balloon, a rubber band, a straw, tape, and an index card or paper with markings.

Procedure:

Cut a balloon and stretch it tightly over the mouth of

the jar, sealing it with a rubber band. Tape one end of a straw to the center of the stretched balloon so the straw sticks out like a pointer. Place the jar beside a vertical index card with a scale marked on it. Over several days, observe how the straw moves up or down.

Physics Behind It:

This homemade barometer works based on atmospheric pressure. When air pressure increases (good weather), it pushes down on the balloon's surface, causing the straw to tilt upward. When pressure drops (often before rain), the balloon surface rises slightly, and the straw points downward. The stretched balloon acts as a flexible diaphragm, responding to external pressure changes. This experiment also shows the compressibility of gases and how pressure differences can cause mechanical motion, a fundamental concept in fluid dynamics and meteorology.

Application:

Real barometers use similar principles to predict weather. Even planes use pressure sensors to measure altitude—air pressure decreases with height.

The Lazy Egg Test

Materials Needed: A raw egg and a hard-boiled egg.

Procedure:

Spin both eggs on a smooth surface. Stop each egg briefly with your finger and immediately lift your finger. The raw egg will start spinning again, while the hard-boiled one will stay still.

Physics Behind It:

This experiment reveals rotational inertia and internal fluid dynamics. When you stop the raw egg, the liquid inside continues moving due to inertia. Since the inside is not rigid, its motion restarts the egg's spin. The hard-boiled egg, being solid, stops completely with no internal motion left to restart rotation. The conservation of angular momentum explains why the internal mass in the raw egg tries to keep spinning. This experiment beautifully connects inertia, angular motion, and energy distribution in rotating systems.

Application:

This method is used to distinguish between raw and boiled eggs. The same physics applies to gyroscopes and spacecraft stabilization, where internal components affect rotational dynamics.

Kitchen Rocket Science

Materials Needed: An empty plastic bottle, vinegar, baking soda, a paper towel, and a cork or bottle cap that fits snugly.

Procedure:

Pour vinegar into the bottle (about ⅓ full). Wrap a spoon of baking soda in a piece of paper towel to make a time-delayed packet. Drop it into the bottle and quickly cork it. Place the bottle on the ground upside down and step back. Within seconds, the bottle launches.

Physics Behind It:

This is a practical demo of Newton's Third Law: for every action, there is an equal and opposite reaction. The reaction between vinegar (acetic acid) and baking soda (sodium bicarbonate) releases carbon dioxide gas. As pressure builds inside the sealed bottle, it forces gas downward. The reactive force pushes the bottle upward. This is also an example of chemical energy being converted to kinetic energy, and demonstrates principles of thrust and conservation of momentum. The reaction chamber (bottle) mimics a real rocket engine.

Application:

Rocket propulsion systems—from fireworks to NASA rockets—use this very principle. Action/reaction forces also explain how we walk: you push the ground backward, it pushes you forward.

Ancient Shadow Clock

Materials Needed: A straight stick (or dowel), a flat surface (like a sidewalk or a piece of cardboard), a ruler or measuring tape.

Procedure:

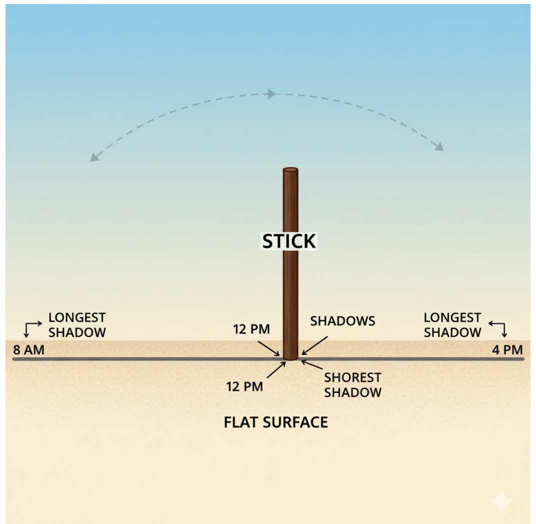
Place the stick vertically in the center of the flat surface. At regular intervals (every hour), mark where the shadow of the stick ends. You will see the shadow change length throughout the day. At noon, the shadow will be the shortest, and it will grow longer as the day progresses.

Physics Behind It:

This experiment demonstrates Earth's rotation. As the Earth rotates on its axis, the angle of the Sun's rays changes, which causes the shadow of the stick to change in length and direction. This is a direct consequence of the Earth's movement and axial tilt. The periodic motion of the Earth is responsible for the daily change in shadow length, which ancient civilizations used to track time, seasons, and even the Earth's movement relative to the Sun.

Application:

Ancient Egyptians, Greeks, and other civilizations built sundials based on similar principles. Today, this principle is still used in calculating time zones and understanding the Earth's axial tilt in relation to seasons.



The Bounce Mystery

Materials Needed:

A ball (preferably a bouncy one, like a superball), a flat surface (such as concrete or hardwood).

Procedure:

Drop the ball from a certain height and observe how high it bounces back. Drop the ball several times, and notice that with each drop, the ball bounces lower.

Physics Behind It:

This experiment illustrates the conservation of energy and energy transfer. When the ball is dropped, its potential energy is converted into kinetic energy as it falls. Upon hitting the ground, some of that kinetic energy is transferred into the

ground and into sound and heat energy, causing the ball to bounce back with less height each time. The decrease in bounce height is due to energy losses, which align with the principles of thermodynamics, where energy is always conserved but can transform into less useful forms.

Application:

This principle is used in the design of sports balls, footwear, and even in analyzing the energy efficiency of vehicles (as they lose energy during collisions). Engineers design systems to minimize these energy losses wherever possible.

Static Butterfly

Materials Needed:

A plastic comb or balloon, a piece of paper cut into the shape of a butterfly, and your hair or a woolen sweater.

Procedure:

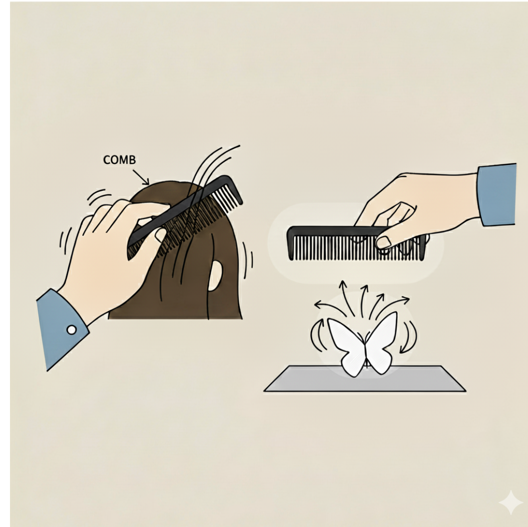
Rub the comb through your hair or on the sweater to build up static electricity. Hold the comb close to the paper butterfly and watch it jump up toward the comb. The paper will even start to "dance" as the static charge is transferred.

Physics Behind It:

This experiment demonstrates electrostatics and charge transfer. Rubbing the comb on your hair transfers electrons from one surface to the other, creating a static charge. The charged comb creates an electric field that interacts with the charged paper butterfly, causing it to be attracted toward the comb. The principle behind this is that opposite charges attract, and like charges repel, which is a fundamental concept in electromagnetism.

Application:

This force is used in many technologies today, including printers that use static charges to apply ink to paper. The phenomenon of electrostatics is also responsible for static cling in clothes and for many lightning strikes.



Impossible Utensil Balance

Materials Needed:

A spoon, a fork, a toothpick, and a glass.

Procedure:

Interlock the spoon and fork, then place them on the edge of a glass, balancing them so that the center of mass of the two utensils is directly over the pivot point (the edge of the glass). Place the toothpick across the middle, supporting the utensils on both sides. The utensils will balance on the toothpick despite their odd shape.

Physics Behind It:

This experiment demonstrates the concept of center of mass and equilibrium. The center of mass of the fork and spoon system is positioned directly over the pivot point (the edge of the glass), so the system remains balanced. If the center of mass were off-center, the system would topple. The toothpick acts as a simple support structure, and the balance relies on the careful positioning of the objects to ensure their combined weight is evenly distributed.

Application:

This principle is applied in engineering, where cranes and other heavy lifting devices use the center of mass to maintain balance and prevent tipping. In vehicle design, ensuring the center of mass is properly placed helps in making cars more stable.

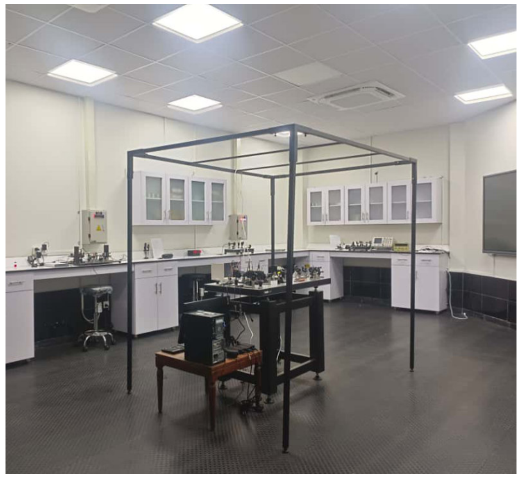
> **"Experiment is the sole judge of scientific truth.'"**
> **— Richard Feynman**

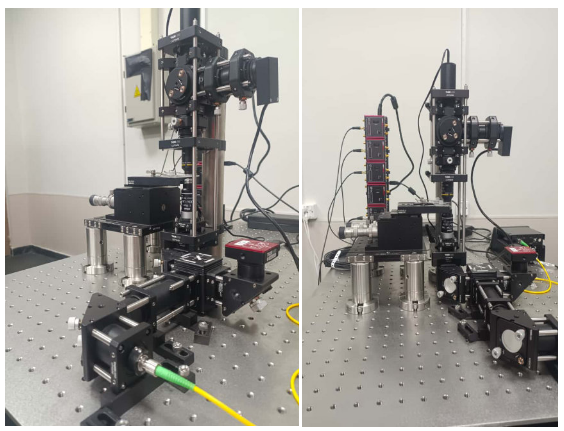
Quantum Science and Technologies at PIEAS

The Department of Physics and Applid Mathematics at PIEAS hosts a network of Quantum Science and Technologies (QST) laboratories that bridge theory with experiment, advancing research in optics, communication, computation, and quantum foundations. These five laboratories collectively form the cornerstone of quantum education and research at PIEAS.

1. Basic Quantum Physics Laboratory

The Basic Quantum Physics Laboratory serves as a bridge between the classical and quantum regimes of light. Established with the support of the Turkish Cooperation and Coordination Agency (TIKA) and the Higher Education Commission (HEC), it is equipped with Michelson Interferometer and Fourier Optics modules that enable students to explore interference, diffraction, and coherence—concepts essential for understanding the wave nature of light. This foundation extends into the quantum domain through experiments with attenuated light and single photons, demonstrating phenomena such as quantum interference and photon antibunching. By linking classical wave behavior to quantum optical effects, the lab builds a clear conceptual pathway toward advanced studies in quantum technologies.





2. Optical Tweezer Laboratory

The Optical Tweezer Laboratory introduces students to the manipulation of microscopic matter using focused laser beams. Optical tweezers trap and control particles like microbeads or cells without physical contact, demonstrating how light can exert measurable forces. This technique, recognized by the 2018 Nobel Prize in Physics, provides insights into biophysics, nanomanipulation, and emerging quantum control systems. By offering hands-on experience with optical alignment and feedback control, the laboratory lays the groundwork for advanced explorations in neutral-atom quantum computing architectures and other atomic-scale technologies.

3.Quantum Optics Lab

This lab focuses on the experimental investigation of light–matter interactions at the quantum scale. Students explore quantum phenomena such as single-photon interference, entanglement, and coherence, which underpin emerging quantum technologies. The Quantum Optics Lab provides the foundation for advanced studies in quantum sensing, quantum imaging, and quantum information, connecting theoretical principles to real-world photonic applications.

4. Quantum Communication Lab

The Quantum Communication Lab investigates secure data transmission using the laws of quantum mechanics. Here, researchers implement protocols like Quantum Key Distribution (QKD) to study how quantum states of light can encode and share information safely. The lab emphasizes synchronization, signal detection, and key-sifting algorithms, enabling students to gain practical experience in quantum cryptography and the development of next- generation communication networks.

5. Computational Quantum Research & Automation Laboratory

The Computational Quantum Research & Automation Lab integrates quantum simulation, programming, and automation to support experimental and theoretical research. Students use tools such as QuTiP and Qiskit to model quantum systems, simulate QKD and quantum imaging, and develop control software for experiments. This lab bridges computation and experimentation, preparing students for future work in quantum computing and automated quantum research.

Igniting Ingenuity: Pakistan's Stem Elite

A Joint Venture by HEC and PIEAS is identifying and nurturing the nation's brightest young minds to secure the future of Science, Technology and Mathematics.

Tlopmhe STEM Careers Program is a joint initiative of the Higher Education Commission (HEC) and the Pakistan Institute of Engineering & Applied Sciences (PIEAS). It aims to motivate and empower the nation's youth to pursue impactful careers in Science, Technology, Engineering, and Mathematics (STEM). The program also prepares talented students to represent Pakistan at prestigious International Science Olympiads (ISOs) in Biology, Chemistry, Mathematics, and Physics—showcasing the nation's remarkable scientific potential and excellence on the global stage. Through this initiative, young minds are nurtured and inspired to become future innovators, researchers, educators, and leaders driving scientific progress and national deveent.

The STEM Careers Program has a twofold mission:

- To inspire the nation's youth to pursue careers in science, mathematics, and engineering, while preparing them to represent Pakistan in the annual International Olympiads in Physics, Chemistry, Biology, and Mathematics.
- To encourage engineering students to develop innovative and practical solutions to challenges of national importance.

Registration & Selection Process

1. Nationwide Screening Test conducts in the major cities .
2. *Top 50 students* are invited for one week fully residential training camp in each of the NSTC subject on the basis of their performance in the Screening Test. The grooming/selection process gradually narrows down this number to 4-6 best students in each of these subjects.
3. *Olympiad teams of 4-6 students* are selected through a series of subsequent training camps during a year for participation of International Science Olympiads to represent their country.

Eligibility Criteria for National Screening Test

Aggregate marks of 60% or more in core subjects ,i.e. Physics ,Chemistry ,Biology and Mathematics in last exam. Age less than 20 years at the time of participation in ISOs.

Pakistan is regularly participating in the International Physics Olympiad since 2001, in the Mathematics Olympiad since 2005, in the Biology and Chemistry Olympiad since 2006 and in the Nuclear Sciences Olympiad since 2024. The performances of Pakistani teams in these Olympiads have been quite encouraging.

	Gold	Silver	Brownze	Hounourable Mentsion
Physics	0	1	16	32
Mathematics	0	2	9	27
Biology	1	2	23	10
Chemistry	0	0	20	1
Nuclear	1	3	4	0
Total	2	8	72	70

About PIEAS Society for Physics

The PIEAS Society for Physics (PSP) is a vibrant community of students driven by curiosity and a shared love for understanding how the universe works. PSP strives to make physics more than just a subject — a living experience. Through integration competitions, Space Week, outreach programs, and live experiments, it transforms abstract ideas into exciting explorations. By inviting alumni and researchers to share their insights, the society helps students see the broader horizons of scientific pursuit. At its heart, PSP is about learning, discovery, and the joy of seeing physics come alive beyond the classroom.

"Somewhere, something incredible is waiting to be known."
— Carl Sagan

PIEAS Society for Physics
Unravelling Beyond Horizon

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