Institute of Physics Alumni Association

E C H O - 2 0 2 6

The Voices That Resonate

Celebrating memories, achievements, and the bonds, that connect generations of researchers presented to you by the

IOP community

September 3, 2026
Institute of Physics, Bhubaneswar

the TEAM of ECHO

envisioned by	Digbijaya Palai
coordinated by	Sairam Ithineni
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We extend our heartfelt gratitude to all the distinguished professors and alumni who generously shared their time, memories, and insights with us. We are equally thankful to every contributor whose creativity, dedication, and thoughtful work helped bring this magazine to life. This publication is a collective celebration of the people and stories that make our community special, and we sincerely appreciate everyone who contributed to its creation.

the TEAM of Alumni Association

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Director's Note

From Student to Director: Coming Home to IOP

Prof. Bedangadas Mohanty
Predoc-1997 batch • Experimental High Energy Physics

IOP holds a very special place in my life. I came here as a doctoral student in July 1997. I initially worked in experimental condensed matter physics and, during my time here, moved to experimental high-energy physics, a field that has remained at the heart of my scientific journey ever since. More importantly, it was at IOP that my interest and excitement for research were truly kindled.

Nearly three decades later, to re-enter the same Institute as its Acting Director has brought that journey full circle in a way I could never have imagined as a young student. I entered IOP with the privilege of learning from it; today, I have the privilege and responsibility of serving it. It is both an honour and a deeply humbling experience to contribute, in whatever way I can, to an institution that contributed so much to shaping my own scientific life.

Alumni Day on 3rd September also brings back many fond memories. I particularly remember one year when we invited the legendary cartoonist R. K. Laxman, whose cartoons in The Times of India were familiar to generations of Indians. I was given the responsibility of looking after him during his visit. We were mesmerised as he drew cartoons on stage, seemingly effortlessly. At the end of his visit, he gifted me a sketch of Ganesha. It remains one of my treasured memories of those days and, even today, that drawing adorns a wall of my home.

Over the years, IOP alumni have spread far and wide, taking up faculty and research positions at institutions across India and abroad and contributing to science and society in many different ways. Yet, wherever our individual journeys have taken us, I believe we continue to carry something of IOP with us.

It is therefore particularly meaningful for me to see Alumni Day being revived after a gap of several years. I hope it once again becomes a lasting IOP tradition, a day to return, reconnect with friends and teachers, share memories and journeys, and strengthen the bond between the Institute and generations of its alumni.

I warmly welcome our alumni back to IOP on 3rd September and wish everyone a very happy and memorable Alumni Day.

Registrar's Note

Lt. Col. Bibekananda Pattanaik

Dear Alumni, Friends, and Well-Wishers of IOP, it gives me profound happiness to greet you all on the historic occasion of our Annual Foundation Day. This year, our celebration is extra special as we release the inaugural edition of our Alumni E-Magazine. Since its inception, the Institute of Physics (IOP) has grown into a premier destination for advanced research, driven by the passion of its faculty, students, and administrative staff. But the true measure of our success lives in you - our alumni - who carry the spirit of IOP into laboratories, classrooms, and institutions across the world.This e-magazine aims to bridge the distance between your alma mater and your current journeys. It is a canvas to share your stories, celebrate your milestones, and keep the collaborative pulse of our scientific family beating strong.

As we turn this new page, I invite you to view this publication as your own. Stay connected, share your feedback, and continue to inspire the generations of physicists walking our corridors today.

Wishing you great success in all your endeavors.

Warm regards & best wishes.

Jai hind.

Dean’s Note

Prof. Arijit Saha
Year of joining - 2015 • Theoretical Condensed Matter Physics

It is my distinct honor and privilege to welcome our esteemed alumni back to the campus on the occasion of Alumni Day (3rd September, 2026).

Institute of Physics (IOP), as an institution cannot be defined by its buildings and classrooms only, but by the achievements of its students, faculty members go on to lead in the fundamental research worldwide. Each one of you carries forward the values, curiosity and commitment that form the core of our academic philosophy and integrity. Your achievements across diverse fields of physics research, teaching, public service and academia- are source of immense pride for us and beacon of inspiration for our current students and faculties.

Alumni Day is more than a reunion. It is a bridge between legacy and possibility. It is an opportunity for our students to learn from your journey, for our faculty to reconnect with their purpose, and for you to witness how your almameter continues to evolve.

On behalf of the academic fraternity, I extend my heartfelt gratitude for your continued engagement, mentorship and support. May this day strengthen our bond and renew our shared commitment to the excellence, innovation and service to the society and nation.

Welcome home.

Content

The Great Conjunction

A verse from the winter sky, December 21, 2020

Abhishek Hota
Predoc-2023 batch • Theoretical Condensed Matter Physics

This was written during my master's, back home, long before I had any idea I would one day join the Institute of Physics.That winter, in the middle of the pandemic, with everything else on pause, I remember stepping out one night and looking up to see Jupiter and Saturn closer together than they'd been in almost four hundred years. I didn't know then what path I was headed towards, but watching those two old giants slowly drawing near felt like something worth putting into words.

Let's fly alongside,
With light into the dark side
To connect, to create
To explore, to consolidate.
Beyond the pale yellow dot,
Far from the red orb.

I can see a never-ending darkness,
Enduring my curiosity.
And there, there,
Two giants floating in the Einstein's layer,
One is named after a Roman God, the other a Greek God.
One has a giant red spot, the other a ring, rhythmically even and odd.
Separated by an unimaginable distance,
Both revolve around the Sun, a star which can give life a chance.
They revolve and revolve,
In a time scale where humanity involves.

We are able to observe, we are able to preserve
The knowledge, the wisdom, for the future,
After four hundred years of revolution,
Here we are, watching the great celestial conjunction.

Beyond the Poster:
A PhD Scholar's Singapore Odyssey

A journey to attend the international conference at NUS Singapore

Ashis Kumar Panigrahi
Predoc-2022 batch • Experimental Condensed Matter Physics

Chapter 1 : The Email That Changed Everything

Every PhD scholar remembers one email.
Not the one reminding us of committee meetings.
Not the one asking for corrections.
But the one that quietly says,
"Congratulations! Your poster has been selected."
That single sentence transformed months of sleepless nights into a boarding pass to another world.

For years my life had revolved around Raman spectra, photoluminescence peaks, transfer curves, mobility calculations, reviewers' comments, and endless cups of tea in the Institute of Physics, Bhubaneswar. My laboratory had become my second home, and my computer screen had become my window to the microscopic universe of two-dimensional materials.
Now, suddenly, that microscopic universe was taking me across international borders.
I was going to Singapore.
The excitement was mixed with panic.
Passport?
Visa?
Poster tube?
Laptop?
Conference registration?
Foreign currency?
Every checklist seemed incomplete.

The real adventure began even before reaching Singapore.

Our flights were scheduled mostly at night.

Sleeping on airplanes looks glamorous only in advertisements. In reality, it is an Olympic event involving neck pain, uncomfortable seats, crying babies, and trying not to disturb the stranger beside you.

By the time we reached Changi Airport, my biological clock had officially resigned from its duties.

Little did I know...
...this was only the beginning.

Chapter 2 : Lost in the Future

The first impression of Singapore wasn't its skyscrapers.

It was silence.

Everything worked.
Everything was automated.
Everything happened exactly on time.
Even the airport seemed smarter than me.
Doors opened automatically.
Trains arrived automatically.
Ticket gates opened automatically.
Even the hotel doors seemed to judge

my intelligence before allowing me inside.

The first challenge arrived in the form of the MRT.
Confidently, I entered the metro like an experienced international traveler.
Five minutes later... I realized I was traveling in the wrong direction.
After politely asking a few passengers, I finally corrected my route. That was my first lesson:
“Technology is wonderful... until you don’t know where you’re going.”

The second lesson nearly cost me 500 Singapore dollars.
Feeling thirsty after walking endlessly, I was about to drink water inside the metro.
My friends immediately stopped me.
“No! Don’t!”
Apparently eating or drinking inside Singapore’s metro is prohibited.
At that exact moment I silently thanked my friends for saving not only my wallet but probably my remaining dignity as well.

For the first two days, I had another opponent.
The National University of Singapore campus.
Calling NUS a “campus” feels unfair.
It is practically a city.
Every building looked important.
Every road looked identical.
Every turn looked familiar.
Yet somehow I always managed to reach the wrong destination before reaching the correct one.
Google Maps itself seemed confused.

By the second day, I had accepted that getting lost in NUS was simply part of the orientation program.
Meanwhile, something else surprised me.
There were very few motorcycles.
Cars and buses dominated the roads.
Delivery riders were practically the only people using bikes.

Traffic followed rules so perfectly that crossing roads without waiting for signals almost felt illegal even when no vehicles were around.

As an Indian, it felt fascinating.
Different.
Disciplined.
Beautiful.
And slightly lonely.
People respected personal space so much that conversations with strangers were rare.

For someone accustomed to India’s lively streets and spontaneous interactions, the silence sometimes echoed louder than the traffic.

Chapter 3 : The Scientist Takes the Stage

Then came the reason I had traveled thousands of kilometers.

The conference.
Walking into the venue felt like stepping inside a global laboratory.
Researchers from every corner of the world discussed atomically thin materials as casually as people discuss cricket scores back home.
Every poster represented years of someone’s life.
Every presentation reflected countless failed experiments before one successful result.
Then came my turn.
Standing beside my poster, I suddenly realised something profound.
Months earlier, these figures had existed only inside my laboratory note-

book.

Now scientists from different countries were stopping, reading, asking questions, appreciating my work, challenging my interpretations, and discussing new ideas.
The conversations were intense.
Band structures.
Excitons.
Interlayer coupling.
Charge transport.
Graphene.
MoS_2.
Device physics.
Questions arrived one after another.
So did confidence.
Every discussion improved my understanding of my own research.

Science, I realised, isn't simply about publishing papers.
It is about conversations.
The conference wasn't merely a place to present results.
It became a place where ideas traveled faster than airplanes.
Ironically...

The only thing that failed to excite me wasn't the science.
It was the food.
The meals looked elegant.
Five-star elegant.
Unfortunately, many dishes revolved around beef, pork, lamb, or foods unfamiliar to my taste. As an Indian who instinctively searches for rice, roti, or dal, I quietly surrendered.

Soon I discovered my sanctuary.
An Indian restaurant.
There, the humble combination of cheese paratha and hot chai became more satisfying than any gourmet international buffet.
Nothing teaches patriotism faster than missing Indian food abroad.

Chapter 4 : The City That Looked Like Tomorrow

Once the conference sessions ended each day, Singapore transformed into an open-air engineering exhibition.
Marina Bay looked unreal.
The skyline reflected perfectly on the water, making the buildings appear twice as magnificent.
The Merlion stood proudly, silently watching millions of tourists attempting impossible camera angles.
Sentosa Island felt like a world built purely for imagination.
The Jewel at Changi Airport looked less like an airport and more like science fiction made real. Waterfalls inside buildings.
Gardens inside airports.
Architecture blending seamlessly with nature.
Everywhere I looked, I saw human creativity challenging conventional engineering.
As a scientist, I admired the precision.
As a traveler, I admired the beauty.

As an Indian...
...I wondered how people actually remembered all these metro routes.

During these explorations, I also met Indian students studying in Singapore.
Speaking in familiar accents after days of hearing different languages instantly felt comforting.
For a brief moment, Singapore felt less foreign.
And a little more like home.

Chapter 5 : One Hour Before Disaster

Every great journey deserves a dramatic ending.
Mine almost missed the flight.
After days of traveling, presenting, walking, exploring, and surviving on interrupted sleep, exhaustion finally defeated us.
At Changi Airport we decided to rest for a while.
Just a short nap.
The airport was so peaceful that sleep arrived almost instantly.

When I opened my eyes...
Panic.
Our flight was barely about an hour away.
Suddenly the world's most beautiful airport transformed into a race track.
Bags.
Passport.
Laptop.
Boarding pass.
Run.

By some miracle-and perhaps a generous contribution from destiny-we reached just in time.
The return journey gave me enough time to reflect.
I had traveled abroad for the first time to represent my research.
I had spoken with international scientists.
Presented my work confidently.
Learned from experts.
Got lost in one of the world's best universities.
Almost paid a 500 SGD fine without knowing.
Survived conference food by discovering cheese paratha and chai.
Admired futuristic architecture.
Made unforgettable memories.
And somehow returned home with stories more valuable than souvenirs.
When the aircraft finally landed in India, I smiled.

Singapore had amazed me.
Its discipline, infrastructure, technology, cleanliness, and architecture were truly extraordinary.
But stepping back onto Indian soil reminded me of another truth.
Home isn't always the most perfect place.
It is simply the place where your heart feels understood.
Singapore showed me what humanity

can build.
India reminded me why I belong.
And somewhere between Raman spectra, airport naps, automated doors, cheese parathas, and scientific discussions, I realised that conferences are never just about presenting research. They are about discovering the world- and, sometimes, discovering yourself.

The End... or perhaps just the beginning of many more scientific journeys.

From Sundial to Satellite

The Story of How Humanity Learned to Measure Time - from Shadow Sticks to the Global Positioning System

Aswin Kumar Burma
Predoc-2021 batch ● Experimental Condensed Matter Physics

Long before the first gear turned or the first spring coiled, a farmer in the Nile valley planted a wooden stick in the ground and watched its shadow creep across the sand. That simple act - reading the sun's passage to divide a day into portions - was humanity's first watch. Five thousand years later, a soldier checks a wristwatch that quietly listens to signals from satellites orbiting 20,000 kilometers overhead, satellites whose onboard clocks have been deliberately mistuned to compensate for the bending of time itself, as predicted by Einstein. Between the shadow stick and the satellite lies one of the most quietly spectacular stories in the history of science: the story of how our species learned, with ever-increasing audacity, to catch hold of time.

This is not merely a story of gears and crystals. It is a story of astronomers and carpenters, of monks who needed to pray on schedule and sailors who needed to avoid running their ships onto rocks, of a physicist who quietly proved Einstein right without ever setting out to, and of the improbable fact that the phone in your pocket is, at this very moment, doing relativistic physics so that your map app knows which street you are on. This article traces that journey - from the ancient sundial to the modern GPS-synchronised clock - for readers who, like the researchers of this institute, share a fascination with how ingenuity accumulates, decade after decade, into revolutions.

I. Reading the Sky: Timekeeping in the Ancient World: The earliest timekeepers did not build instruments; they read the sky. The ancient Egyptians were among the first civilisations to divide the day into agreed, equal parts, using shadow clocks, obelisks and merkhets - plumb-lines used by priest-astronomers to track the stars. The oldest surviving sundial, a limestone device unearthed in the Valley of the Kings in 2013, dates to roughly 1500 BCE and appears to have been used to measure the working hours of construction labourers - perhaps making it history's first timesheet.

Table 1: A Timeline at a Glance

Period	Milestone
c. 3500 BCE	Egyptians raise the first gnomons and obelisks; shadow-length tells the hour.
c. 1400 BCE	The klepsydra (water clock) appears in the temple of Amen-Re at Karnak, freeing timekeeping from sunlight.
13th century CE	The verge-and-foliot escapement is invented in Europe, giving birth to the mechanical clock.
1500–1510	Peter Henlein of Nuremberg builds spring-driven portable clocks - ancestors of the watch.
1656	Christiaan Huygens builds the first working pendulum clock, slashing daily error from hours to seconds.
1761–1770	John Harrison perfects the marine chronometer (H4), solving the longitude problem at sea.
1880–1918	The wristwatch moves from military novelty to standard-issue “trench watch” in the First World War.
1955	Louis Essen and Jack Parry build the first practical caesium atomic clock at NPL, UK.
1969	Seiko launches the Quartz Astron, igniting the global quartz revolution.
1978–present	The GPS constellation links orbiting atomic clocks to deliver time and position worldwide.

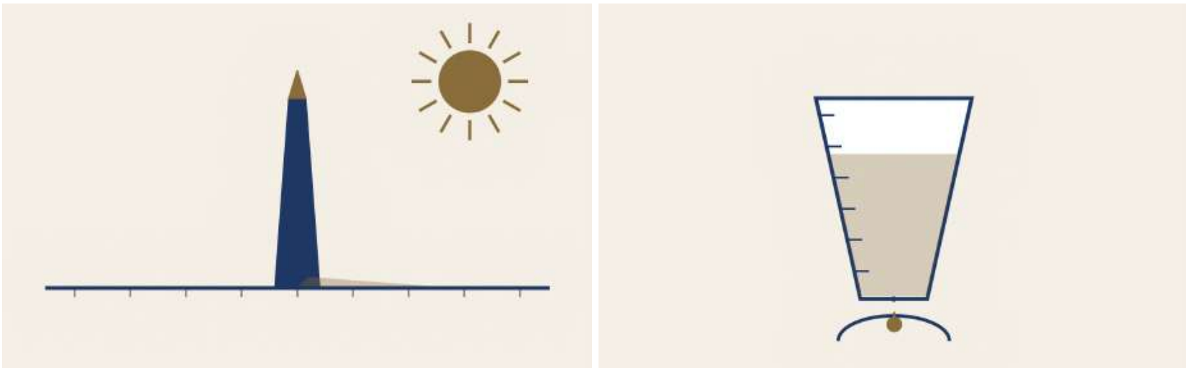


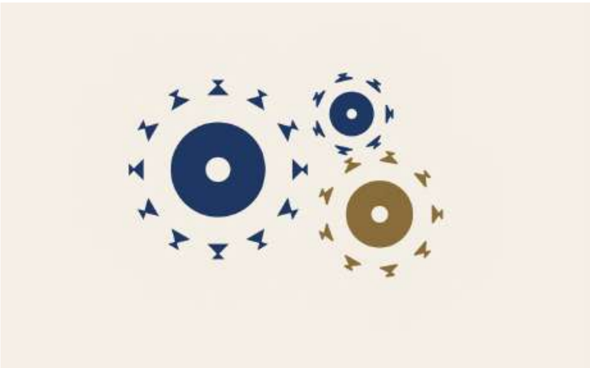
Figure 1: (left) The obelisk sundial: Egypt’s earliest instrument for dividing the day by the sun’s shadow. (right) The klepsydra, or water clock: graduated markings tracked time as water drained at a steady rate.

But the sundial had an obvious flaw: it needed the sun. To tell time after dusk or under cloud, the Egyptians invented the klepsydra, or water clock - a stone or pottery vessel that drained at a steady rate through a small hole, with marks along its inner wall denoting the passing hours. The oldest surviving example dates to the reign of Pharaoh Amenhotep III, roughly 1417 - 1379 BCE, and a tomb inscription credits a court official named Amenemhet with the invention. From Egypt, the idea travelled to Babylon, Greece and China, where by the sixth century CE, monks were burning graduated incense sticks to mark the hours in temples. The Greeks, borrowing the Babylonian base-60 counting system, began dividing hours into sixty minutes - a scheme so durable that it still governs every clock face on Earth.

> DID YOU KNOW?
> Herodotus credited the Babylonians with inventing the sundial around 430 BCE - but archaeological evidence now traces simple shadow-clocks in Egypt back roughly two thousand years earlier.

II. Ticking Machines: The Birth of the Mechanical Clock: For all their ingenuity, sundials and water clocks were tied to nature's rhythms. The true break came in thirteenth-century Europe with the invention of the verge-and-foliot escapement - a mechanism of a toothed "crown wheel" and a swinging bar that let a weight-driven gear train advance one notch at a time, producing the world's first reliable mechanical tick. Bulky verge clocks soon crowned the towers of European monasteries and town halls; a documented example built by Henri de Vick for the King of France in 1379 struck the hours over Paris. These clocks were wildly inaccurate by modern standards - errors of an hour or two a day were common - because their rate depended on unpredictable friction and driving force, much like water pressure through a leaking pipe.
The next leap made timekeeping personal. Between 1500 and 1510, the locksmith Peter Henlein of Nuremberg began building small spring-driven clocks that, freed from hanging weights, could sit on a shelf - or even be carried. They ran slower as their mainspring unwound and kept poor time, but they were the direct ancestors of the portable watch, and wealthy Europeans prized them as much for status as for accuracy.

III. The Pendulum Revolution: Galileo Galilei is said to have first studied the steady rhythm of a swinging pendulum in 1582, reportedly while watching a lamp sway in Pisa Cathedral, and he sketched a pendulum-regulated clock late in his life - but he died before it could be built. It fell to the Dutch polymath Christiaan Huygens to complete the idea. In 1656, Huygens built the first working pendulum clock, and the effect was immediate and dramatic: daily error fell from roughly fifteen minutes to about fifteen seconds, an improvement of nearly sixty-fold in a single stroke.



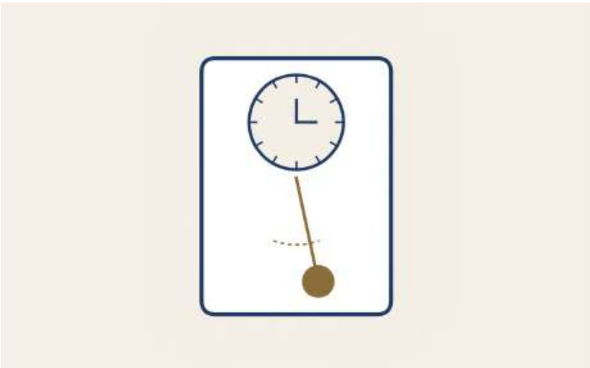


Figure 2: (left) The verge-and-foliot escapement: interlocking gears produced the world's first reliable mechanical tick. (right) Huygens's pendulum clock (1656): a regular swing cut daily error from minutes to seconds.

> In one stroke, Huygens turned the clock from an approximate reckoner of the hour into a genuine scientific instrument.

Huygens did not stop there. Recognizing that wide pendulum swings introduced their own errors, clockmakers developed the anchor escapement around 1670, narrowing the pendulum's arc and improving accuracy further still. In 1675, Huygens also devised the balance wheel and hairspring assembly - a coiled spring that could regulate a small oscillating wheel instead of a swinging pendulum. This single invention made accurate portable watches possible for the first time, and variants of the balance spring survive in mechanical watches made even today.

IV. Racing the Sun: By the early eighteenth century, a ship's captain could measure latitude with reasonable confidence by observing the height of the sun or the stars. Longitude - one's position east or west - was another matter entirely, and getting it wrong could be catastrophic. In 1707, a Royal Navy fleet, unsure of its position in fog, wrecked on the Scilly Isles off the English coast, killing well over a thousand sailors. The disaster spurred Parliament to pass the Longitude Act of 1714, offering a vast prize - up to twenty thousand pounds, a fortune at the time - to anyone who could devise a reliable method of finding longitude at sea.

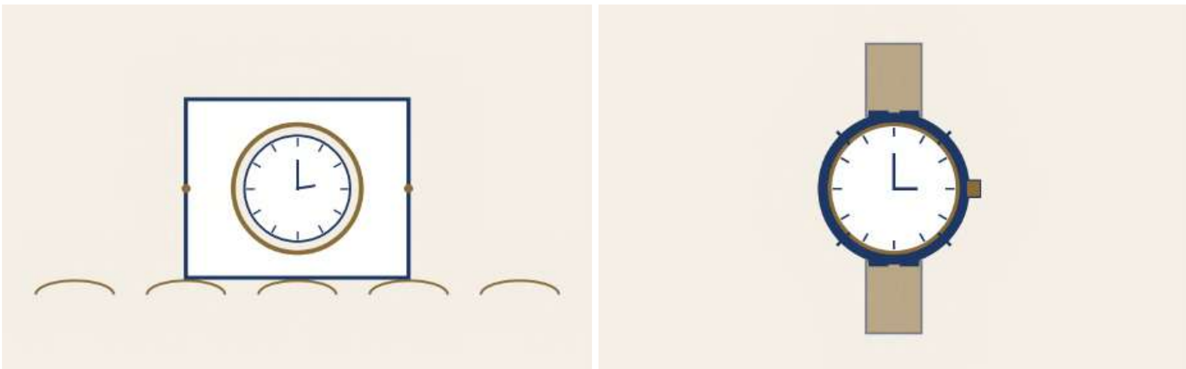


Figure 3: (left) A gimballed marine chronometer, kept level against a ship's roll to hold Greenwich time at sea. (right) The wire-lugged "trench watch" of the First World War, the direct ancestor of the modern wristwatch.

The winning idea was elegant: if a ship carried a clock still set to the time at a known reference point, such as Greenwich, its crew could compare that clock's time to local noon (determined by the sun) and calculate longitude directly, since each hour of difference corresponds to fifteen degrees of longitude. The challenge was building a clock that could survive months at sea - pitching decks, salt air, and swings in temperature and humidity - without losing more than a few seconds. Existing pendulum clocks were hopeless on a rolling ship.

The task fell, almost by accident, to a self-taught Yorkshire carpenter named John Harrison. Over more than four decades, Harrison built an extraordinary series of marine timekeepers - H1, a seventy-five-pound machine of interlinked swinging balances unveiled in 1735; H2 and H3, each more refined; and finally H4 of 1761, a portable timekeeper barely larger than a pocket watch, weighing just over three pounds. Captain James Cook carried a copy of H4, made by the watchmaker Larcum Kendall, on his voyages of Pacific exploration and praised it as an indispensable guide. Harrison's chronometer worked so well that by 1815 more than five thousand marine chronometers were in service, and Charles Darwin's HMS Beagle set sail in 1831 carrying twenty-two of them.

DID YOU KNOW?
Harrison's chronometer left more than a solution to longitude. The bimetallic strip he invented to compensate for temperature - two metals bonded together that bend as they expand at different rates - still regulates thermostats and household appliances today, and the caged ball bearings he pioneered are found in machines everywhere.

V. From Pocket to Wrist: The Rise of the Wristwatch: For most of its history, the personal watch lived in a waistcoat pocket, attached to a chain. Wristwatches - then called "wristlets" - existed as early as 1810, when the master watchmaker Abraham-Louis Breguet built one for Caroline Bonaparte, Queen of Naples, but they were regarded as feminine jewellery rather than serious instruments. The first purpose-made men's wristwatch is generally credited to Girard-Perregaux, who supplied the German Navy with them in 1880 so that officers could check the time without fumbling for a pocket watch mid-manoeuvre. British soldiers on India's North-West Frontier adopted similar leather "wristlets" around the same period, and more improvised versions appeared during the Boer War of 1899 - 1902.

It was the First World War that truly transformed the wristwatch's fortunes. Coordinating artillery barrages, infantry advances and naval manoeuvres demanded that officers check the time instantly, without digging through a pocket under fire. Manufacturers such as Omega, Longines, Elgin and Waltham mass-produced sturdy "trench watches" with luminous radium dials, shatter-resistant crystals and screw-down cases to withstand mud and damp. By the time the United States entered the war in 1917, nearly all watch advertising had shifted from pocket watches to wristwatches, and returning soldiers carried the habit home with them. The wristwatch, once dismissed as effeminate, emerged from the trenches as a badge of modernity - and has remained on the human wrist ever since.

VI. Crystal Clear: The Quartz Revolution: Mechanical watches, however finely made, remained hostage to the imperfections of springs, gears and friction. The next transformation came not from a better mechanism but from a different physical principle altogether: the piezoelectric effect, by which a quartz crystal vibrates at an extremely stable frequency when an electric current is applied to it. Engineers in Japan had already used bulky quartz timers as backup clocks for the marathon event at the 1964 Tokyo Olympics. Five years of miniaturisation later, on Christmas Day 1969, Seiko unveiled the Quartz Astron 35SQ - the world's first quartz wristwatch.

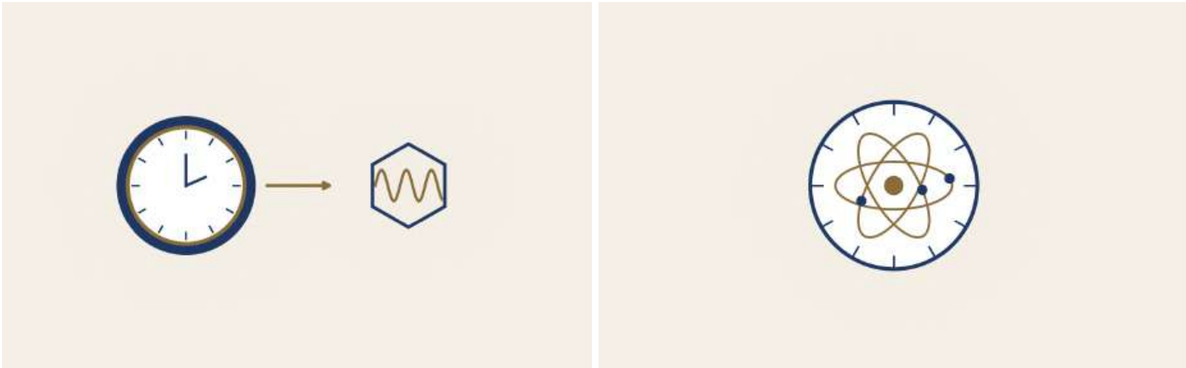


Figure 4: (left) A vibrating quartz crystal replaced springs and gears, giving the 1969 Seiko Astron near-scientific accuracy. (right) The caesium atom's unvarying oscillation now defines the second itself.

The Astron was roughly a hundred times more accurate than a fine mechanical watch, drifting by only about five seconds a month. Seiko's own advertising made a bold and, as it turned out, entirely accurate prediction: "Someday, all watches will be made this way." Within a decade, cheap, mass-produced quartz movements had triggered what the Swiss watch industry still calls the "quartz crisis," reshaping an entire global trade. Quartz technology also achieved something no mechanical watch ever had: it placed near-scientific timekeeping accuracy on every wrist, not merely the wealthiest ones.

VII. Atoms as Clocks: The Atomic Age: Even quartz crystals drift slightly with age and temperature. For applications demanding true precision - astronomy, telecommunications, and eventually satellite navigation - scientists turned to the atom itself. Every caesium-133 atom, when it flips between two particular energy states, absorbs or emits radiation at an identical, unvarying frequency: a natural pendulum, immune to wear, temperature or the passage of centuries.

In 1955, physicists Louis Essen and Jack Parry built the first practical caesium atomic clock at the National Physical Laboratory in the United Kingdom, achieving an accuracy of about one second in three hundred years - roughly thirty times better than the best quartz clocks of the day. The achievement was so compelling that in 1967 the world's metrologists redefined the second itself: one second was fixed as the duration of exactly 9,192,631,770 oscillations of the radiation emitted by a caesium-133 atom, permanently replacing definitions based on the Earth's rotation. Modern "fountain" atomic clocks, such as the NIST-F2 in the United States, which gently toss laser-cooled caesium atoms upward like water from a fountain to extend their measurement time, are now accurate to roughly one second in three hundred million years.

DID YOU KNOW?
When the first GPS satellite carrying a caesium clock was launched in 1977, engineers deliberately left its relativistic correction switched off for twenty days. The clock drifted exactly as Einstein's equations predicted - an inadvertent, orbiting confirmation of relativity.

VIII. Time from Space: GPS and the Physics of Position: The Global Positioning System represents the ultimate synthesis of this five-thousand-year story. Each of the roughly thirty satellites in the GPS constellation carries several atomic clocks accurate to within a few billionths of a second. A receiver on the ground or in your pocket calculates its position by comparing the arrival times of radio signals from at least four visible satellites and triangulating - more precisely, trilaterating - its location from the tiny differences. Because radio waves travel at the speed of light, a timing error of just one microsecond translates to a position error of roughly three hundred meters, which is why the clocks must be extraordinarily precise.

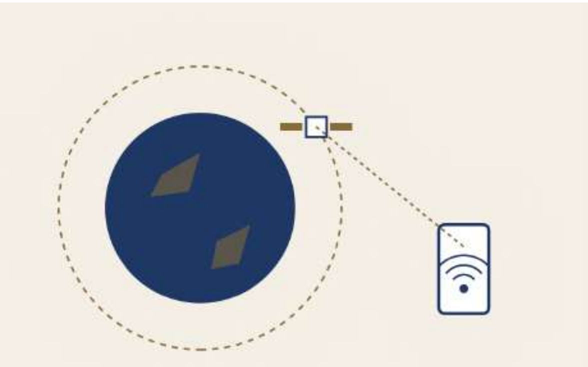


Figure 5: Orbiting atomic clocks and relativistic corrections let GPS satellites pinpoint a receiver on Earth.

Here the story loops back, unexpectedly, to Einstein. GPS satellites orbit at about 14,000 kilometers per hour and sit roughly 20,000 kilometers above the Earth, in much weaker gravity than we experience on the surface. Special relativity predicts that a fast-moving clock runs slow relative to a stationary one, which alone would make each satellite clock lose about seven microseconds a day. General relativity predicts the opposite effect from weaker gravity: a clock farther from Earth's mass runs fast, gaining roughly forty-five microseconds a day. The two effects do not cancel; the net result is that, left uncorrected, every satellite clock would gain about thirty-eight microseconds daily relative to clocks on the ground.

Thirty-eight millionths of a second sounds negligible - until multiplied by the speed of light. Uncorrected, that drift would introduce a positioning error that grows by roughly ten kilometers every single day, rendering the system useless within hours. Engineers solve the problem before a satellite ever leaves the ground: each atomic clock is deliberately manufactured to tick slightly slow, at 10.22999999543 megahertz instead of the standard 10.23 megahertz, so that once relativity speeds it up in orbit, it keeps perfect time with clocks on Earth. It is a striking thought that every smartphone, car and aircraft navigation system quietly depends on a correction for the curvature of spacetime, calculated and built into hardware decades in advance.

> It is a striking thought that finding your way home now depends on a hundred-year-old theory of gravity, and on a clock built to run wrong on purpose so that it will run right in orbit.

IX. The Unbroken Thread: Trace the line from a shadow creeping across Egyptian sand to a caesium atom's silent oscillation to a satellite's relativistically-corrected tick, and a single thread runs through it all: the refusal to accept an imprecise answer to the question "what time is it?" Each generation's most accurate clock became the foundation on which the next generation built something more exact still - the sundial gave way to the pendulum, the pendulum to the balance spring, the balance spring to the quartz crystal, the quartz crystal to the vibrating atom. Today, laboratories are already testing optical atomic clocks, accurate to within a second over the age of the universe, and quantum sensors that may one day make even GPS look primitive.

For a research institute, the history of the watch offers a fitting parable. Progress rarely arrives as a single flash of genius; it accumulates, generation upon generation, through patient observation, stubborn tinkering, and the willingness of scientists and craftsmen alike to ask whether something already thought "accurate enough" might, in fact, be improved. The next time you glance at your watch, phone, or GPS-guided map, it is worth remembering that you are holding the end point - for now - of five thousand years of exactly that kind of persistence.

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Spontaneous symmetry breaking

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Introduction:

Imagine you are sitting at a perfectly round table with a group of friends. In front of everyone are two identical glasses of water—one on the left and one on the right. Everyone is thirsty, but no one knows which glass to pick, since both choices are equally good. So, everyone waits, and the situation remains perfectly symmetric. Suddenly, one person decides to pick up the glass on their right. Seeing this, others follow, and soon everyone is reaching to their right. Nothing about the table or the glasses has changed, yet the group has developed a preferred direction. This simple example captures the essence of *spontaneous symmetry breaking*: the rules of a system may treat several possibilities equally, while the system itself settles into one particular state that no longer has the same symmetry. In short, the laws remain symmetric, but the chosen state does not.

What makes spontaneous symmetry breaking so fascinating is that it appears in places that, at first, seem to have little to do with one another. You will encounter it in familiar phenomena such as magnetism, liquid crystals, superconductivity, and superfluidity. And the story does not end there—spontaneous symmetry breaking also plays a fundamental role in particle physics, for example, in the Higgs mechanism and chiral symmetry breaking.

At first, these phenomena may seem completely unrelated. But once you understand the basic idea, you begin to notice the same story appearing again and again: the laws of physics treat several possibilities equally, yet the system settles into one particular state. So, what does this mean mathematically? Spontaneous symmetry breaking occurs when the underlying laws of motion, described by a Lagrangian or Hamiltonian, possess a symmetry, while the lowest-energy state—the ground state or, in field theory, the vacuum state—does not. As a system parameter is varied, its potential may develop multiple equivalent stable states, and the system can settle into one of them.

In the following sections, we will explore spontaneous symmetry breaking from three different perspectives. We first consider a classical example of a bead on a ring rotating about the z-axis. We then turn to a quantum mechanical example, and finally examine how spontaneous symmetry breaking emerges in statistical mechanics through the Ising model.

A few basics:

Before jumping into our examples, let us briefly introduce a few ideas that will be useful throughout the article. In physics, a *symmetry* means that the description of a system remains unchanged under a particular transformation. For example, if rotating a system does not change its physical description, the system has rotational symmetry. To describe the dynamics of a classical system, we often use the *Lagrangian*,

$$L = T - V, \tag{1}$$

where T and V are the kinetic and potential energies. The action is defined as

$$S = \int_{t_i}^{t_f} L\,dt. \tag{2}$$

The equations of motion follow from the principle of stationary action. This also gives us a convenient way to describe symmetry: if a transformation leaves the action unchanged, the system is said to possess that symmetry. We will also encounter the *Hamiltonian*, which, for a non-relativistic system, represents the total energy,

$$H = T + V. \tag{3}$$

With these ideas in place, let us turn to our first example: a bead constrained to move on a ring rotating about the z-axis.

The classical example: a bead on a vertically rotating hoop:

Let us begin with a simple mechanical system: a small bead constrained to move along a circular hoop of radius R. The hoop is held vertically and rotates about its vertical diameter with constant angular speed ω. The bead's kinetic energy comes from its motion along the hoop and the rotation of the hoop. Taking the gravitational potential energy to be zero at the bottom, the Lagrangian is

$$L = \frac{1}{2}mR^2\dot{\theta}^2 - mgR(1-\cos\theta) + \frac{1}{2}m\omega^2R^2\sin^2\theta. \tag{4}$$

We can write the Lagrangian in the usual form as

$$L = \frac{1}{2}mR^2\dot{\theta}^2 - V(\theta), \tag{5}$$

where, the effective potential is

$$V(\theta) = mgR(1-\cos\theta) - \frac{1}{2}m\omega^2R^2\sin^2\theta. \tag{6}$$

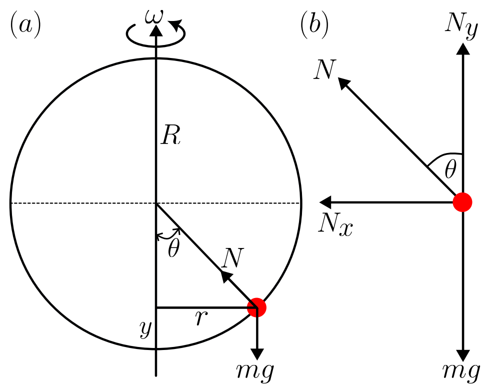

Figure 6: A small bead of mass m constrained to move along a circular hoop of radius R, rotating about its vertical diameter with angular speed ω. (a) The bead is acted upon by gravity and the normal force N exerted by the hoop. (b) Resolution of the normal force into its horizontal and vertical components, N_x and N_y.

Our goal is to find the equilibrium positions of the bead and determine their stability. Equilibrium positions are obtained by setting

$$\frac{dV}{d\theta} = 0. \tag{7}$$

For the effective potential above, this gives

$$\sin\theta\left(g - \omega^2R\cos\theta\right) = 0. \tag{8}$$

The first set of solutions is

$$\theta = 0, \qquad \theta = \pi, \tag{9}$$

corresponding to the bottom and top of the hoop, respectively. There is also another possibility,

$$\cos\theta_0 = \frac{g}{\omega^2 R}. \tag{10}$$

This solution exists only when

$$\omega \geq \omega_c, \qquad \omega_c = \sqrt{\frac{g}{R}}. \tag{11}$$

To see which of these equilibrium positions are stable, we examine the curvature of the effective potential. For $\omega < \omega_c$, the bottom of the hoop, $\theta = 0$, is the only stable equilibrium. At the critical angular velocity $\omega = \omega_c$, this minimum becomes marginal. When the hoop rotates faster than ω_c, the bottom becomes unstable and two new stable equilibrium positions appear symmetrically on either side of the vertical axis:

$$\theta = \pm\theta_0, \tag{12}$$

where

$$\cos\theta_0 = \frac{g}{\omega^2 R}. \tag{13}$$

Something interesting has happened. The two new positions are equally favorable: the bead can settle on either side of the vertical axis. This is not because the equations have changed their preference. In fact, the effective potential satisfies

$$V(\theta) = V(-\theta), \tag{14}$$

so the system remains symmetric under the transformation

$$\theta \to -\theta. \tag{15}$$

Yet, once the bead settles into one of the two stable positions, say $+\theta_0$, the symmetry is no longer apparent in the state of the bead. It could equally well have settled at $-\theta_0$. In an ideal symmetric system, neither side is preferred; in practice, an arbitrarily small perturbation can determine which of the two positions is selected.

This is the basic idea behind spontaneous symmetry breaking: the underlying equations remain symmetric, while the state chosen by the system does not. The rotating hoop therefore provides a simple classical picture of how a single symmetric equilibrium can become unstable and give rise to two equivalent, symmetry-related stable states beyond a critical value of a control parameter. In the next sections, we will see that remarkably similar ideas appear in quantum mechanics and statistical mechanics.

A quantum mechanical example:

We have seen how a classical system can develop two equivalent stable states when a control parameter crosses a critical value. Let us now ask a natural question: *does a similar idea appear in quantum mechanics?*

To explore this, consider a simple system described by a single degree of freedom ϕ with the Lagrangian [4].

$$\mathcal{L} = \frac{1}{2}\dot{\phi}^2 - \frac{1}{2}m^2\phi^2 - \frac{\lambda}{4}\phi^4, \qquad \lambda > 0. \tag{16}$$

The corresponding potential is

$$V(\phi) = \frac{1}{2}m^2\phi^2 + \frac{\lambda}{4}\phi^4. \tag{17}$$

Notice that the potential is unchanged under $\phi \to -\phi$. Thus, the system has a $\mathbb{Z}_2$ symmetry. The shape of the potential depends on the sign of m^2. When $m^2 > 0$, the potential has a single minimum at $\phi = 0$, which respects the $\mathbb{Z}_2$ symmetry. You can notice things become more interesting when $m^2 < 0$. In this case, the minimum at the origin becomes unstable, and two new minima appear at

$$\phi = \pm\phi_0, \qquad \phi_0 = \sqrt{\frac{-m^2}{\lambda}}. \tag{18}$$

We have therefore obtained two equally stable states. The potential still satisfies

$$V(\phi) = V(-\phi), \tag{19}$$

but choosing either $\phi = +\phi_0$ or $\phi = -\phi_0$ selects one of the two symmetry-related states.

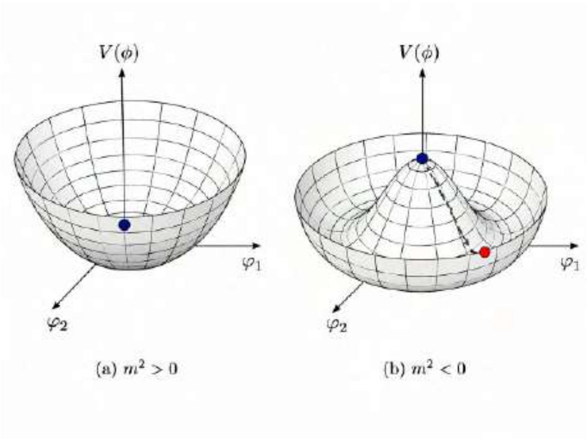

Figure 7: (a) Potential with a single minimum at the origin, corresponding to the symmetric phase ($m^2 > 0$). (b) Double-well potential with two equivalent minima at $\phi = \pm\phi_0$, corresponding to the symmetry-broken phase ($m^2 < 0$).

This is the familiar double-well picture of symmetry breaking. The two minima are completely equivalent: the equations do not prefer one over the other. Once the system is placed in one of the minima, however, the chosen state no longer possesses the original $\mathcal{Z}_2$ symmetry. It is useful to look at the potential more closely. Let us expand around one of the minima, say

$$\phi = \phi_0 + \sigma, \tag{20}$$

where σ describes a small fluctuation about the chosen minimum. Substituting this into the potential gives

$$V(\phi) = V(\phi_0) + \lambda\left(\phi_0^2\sigma^2 + \phi_0\sigma^3 + \frac{1}{4}\sigma^4\right). \tag{21}$$

The important point is not the detailed form of this expansion, but the idea behind it. Once we choose one of the two minima, we describe the system in terms of fluctuations σ around that particular state. The symmetry between the two minima is no longer manifest in the chosen state.

The connection with the classical example:

At this point, the double-well potential may look like a new construction. But we have already seen the same structure in our classical bead-on-a-rotating-hoop example. For the bead, the effective potential can be written in dimensionless form as

$$U(\theta) = (1 - \cos\theta) - \frac{\beta}{2}\sin^2\theta, \qquad \beta = \frac{\omega^2 R}{g}. \tag{22}$$

For $\beta < 1$, there is a single stable minimum at $\theta = 0$. When $\beta > \beta_c = 1$, this minimum becomes unstable and two equivalent minima appear at $\theta = \pm\theta_0$. This is the same basic double-well structure that we encountered above for the potential $V(\phi)$.

In both cases, the potential is symmetric under an inversion,

$$\theta \to -\theta \qquad \text{or} \qquad \phi \to -\phi, \tag{23}$$

while the two stable states are related by this symmetry. The rotating hoop therefore gives us a simple classical picture of the double-well structure.

A subtle quantum twist:

So far, we have discussed the double-well potential from a classical point of view. What changes when we treat the same system quantum mechanically? Classically, a particle placed in one of the two minima can remain there. Quantum mechanically, however, the particle can tunnel through the finite barrier separating the two wells. The two wells are therefore not completely independent.

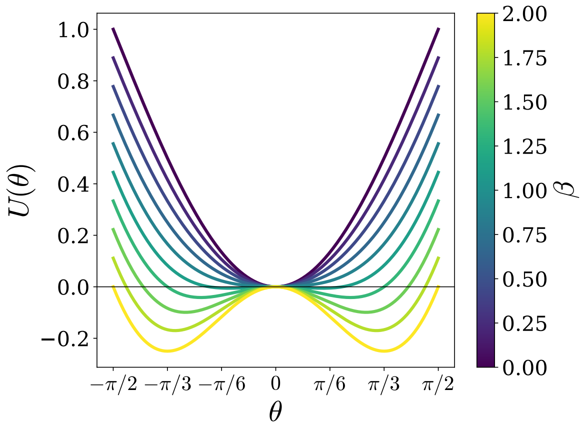

Figure 8: Effective potential $U(\theta)$ as a function of θ for different values of $\beta = \omega^2 R/g$. The potential is symmetric under $\theta \to -\theta$. For $\beta < 1$, it has a single stable minimum at $\theta = 0$. At $\beta_c = 1$, this minimum becomes marginal. For $\beta > 1$, it becomes unstable and two equivalent stable minima appear at $\theta = \pm\theta_0$.

The quantum Hamiltonian is invariant under the parity transformation ($\phi \to -\phi$) as $V(\phi) = V(-\phi)$. Therefore, the energy eigenstates can be chosen to have definite parity. For a sufficiently deep double well, the lowest two energy eigenstates are approximately the symmetric and antisymmetric combinations of states localized in the two wells:

$$|+\rangle \sim |L\rangle + |R\rangle, \; |-\rangle \sim |L\rangle - |R\rangle. \tag{24}$$

The symmetric state is the ground state, while the antisymmetric state lies slightly higher in energy. The small energy splitting between them is a consequence of quantum tunnelling.

This leads to an important difference from the classical picture. A state localized entirely in the left or right well is not, in general, an exact energy eigenstate. Quantum mechanics therefore does not allow a finite one-particle system to simply remain forever in one well as a stationary state. Thus, although the double-well potential has two symmetry-related minima, a finite quantum system does not by itself exhibit spontaneous symmetry breaking. Genuine quantum spontaneous symmetry breaking requires many degrees of freedom and an appropriate infinite-system limit, in which the symmetry-related states can become distinct and tunnelling between them can effectively vanish.

The lesson is subtle but important: *the symmetric double-well potential does not by itself determine whether symmetry is spontaneously broken. We must also consider the quantum states of the system and, for genuine symmetry breaking, the appropriate infinite-system limit.*

Spontaneous symmetry breaking in statistical mechanics:

We have seen how symmetry breaking can appear in a simple classical system, and how quantum mechanics makes the picture more subtle. In statistical mechanics, the idea becomes a truly collective phenomenon. One of the simplest models that captures this behavior is the Ising model, which provides a useful picture of magnetism and phase transitions.

The Ising model:

Imagine a lattice with a large number of sites. At each site, an Ising spin can take one of two values,

$$S_i = \pm 1. \tag{25}$$

For a ferromagnetic interaction, neighboring spins prefer to align. The Ising Hamiltonian is

$$H = -J \sum_{\langle i,j \rangle} S_i S_j - h \sum_i S_i, \qquad J > 0, \tag{26}$$

where J measures the interaction strength and h is an external magnetic field.

When $h = 0$, flipping every spin,

$$S_i \to -S_i, \tag{27}$$

leaves the Hamiltonian unchanged. The model therefore has a $\mathbb{Z}_2$ symmetry:

$$H[S_i] = H[-S_i]. \tag{28}$$

The question is then familiar: *if the Hamiltonian treats the two orientations equally, can the system nevertheless develop a preferred one?*

Temperature and collective behavior: At high temperature, thermal fluctuations tend to disorder the spins, so there is no preferred overall orientation. At sufficiently low temperature, the interaction between neighboring spins can overcome these fluctuations and produce collective magnetic order. The two possible ordered states, with positive or negative magnetization, are equivalent when $h = 0$.

To describe this behavior, we introduce the magnetization,

$$M = \frac{1}{N} \sum_{i=1}^{N} S_i. \tag{29}$$

It acts as an *order parameter*. Under the $\mathbb{Z}_2$ transformation,

$$S_i \to -S_i, \qquad M \to -M. \tag{30}$$

Thus, the two ordered states $M = +M_0$ and $M = -M_0$ are related by the symmetry of the Hamiltonian. The Hamiltonian treats them equally, but the system can select one of them in the thermodynamic limit. This is spontaneous symmetry breaking.

Importance of the thermodynamic limit:

For a finite system at $h = 0$, the equilibrium distribution respects the $\mathbb{Z}_2$ symmetry, and consequently

$$\langle M \rangle = 0. \tag{31}$$

Thermal fluctuations can also take the system from one magnetized state to another. The situation changes in the thermodynamic limit,

$$N \to \infty. \tag{32}$$

In an ordered phase, the two symmetry-related states become separated by a macroscopic free-energy barrier, making transitions between them increasingly difficult. This allows the system to remain in one of the two symmetry-related states.

A useful way to select one of these states is to apply a small positive magnetic field and remove it only after taking the thermodynamic limit:

$$M_s = \lim_{h \to 0^+} \lim_{N \to \infty} M(N, h). \tag{33}$$

Here M_s is the spontaneous magnetization. The order of the limits matters:

$$\lim_{h \to 0^+} \lim_{N \to \infty} M(N, h) \neq \lim_{N \to \infty} \lim_{h \to 0} M(N, h). \tag{34}$$

This non-commutativity is one of the essential features of spontaneous symmetry breaking in statistical mechanics. You could think, why does temperature matter? At low temperatures, the interaction energy favors the alignment of neighboring spins. At high temperatures, entropy favors disorder because there are vastly more disordered configurations than perfectly ordered ones.

The competition is summarized by the Helmholtz free energy, $F = E - TS$. At low temperatures, the energetic advantage of ordering can dominate, while at high temperatures, the entropic advantage of disorder wins. This competition underlies the transition between ordered and disordered phases.

For the short-range Ising model, the details depend on dimensionality. In one dimension, thermal fluctuations destroy long-range magnetic order at any finite temperature. In two dimensions, however, the Ising model has a finite-temperature phase transition: below T_c it has an ordered phase with spontaneous magnetization, while above T_c the magnetization vanishes in the thermodynamic limit.

The statistical-mechanical picture:

The Ising model gives us a many-body version of the idea from our opening analogy. Just as the people around the table could collectively settle on one direction even though the two choices were equivalent, interacting spins can collectively develop a preferred orientation even though the Hamiltonian treats both directions equally. The key difference is that a single object does not make the choice. It emerges from the collective behavior of a very large number of interacting degrees of freedom. This is what makes spontaneous symmetry breaking in statistical mechanics so remarkable. We can therefore summarize the three perspectives discussed in this article as follows:

In the classical mechanics example, symmetry breaking appeared through the structure of the effective potential. In the quantum example, tunnelling showed us why a finite quantum system does not simply remain in one of the symmetry-related wells. In statistical mechanics, many interacting degrees of freedom, thermal fluctuations, and the thermodynamic limit allow a macroscopic system to develop a genuine symmetry-broken phase. The same basic idea has therefore appeared in three very different languages of physics:

> *The laws remain symmetric, but the state chosen by the system does not.*

Looking Back!

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ফিরে দেখা

পিছন ফিরে যদি দেখি পাঁচ-ছয়টা বছর---
ভেসে ওঠে ফেলে আসা একমুঠো রোদ্দুর,
ছায়া সুনিবিড় পাখির কলতানে ভরা এক নীড়।
যেথা আকাশ কুসুম কল্পনাগুলো হারিয়ে যেত
স্টুডেন্ট মেসের প্রাতরাশের বাস্তবতায়।
যেথা গল্প আড্ডার মাঝে হারিয়ে যেতাম বিজ্ঞানের গভীরে---
সাপে-নেউলে থাকা ইলেকট্রনগুলো কখনো উপহার দেয় ফেরো ম্যাগনেট।
আর সেই ইলেকট্রন হঠাৎ করে ফোননের হাত ধরে সুপারকনডাক্টিভিটি নামের বন্ধুত্ব হয়ে হঠা।
বাইলেয়ার গ্রাফিন বলে আমি আড়ি-ভাব দুটোতেই আছি।
ইনসুলেটর স্পিন-অরবিট কাপলিং এর দয়ায় বলে ওঠে আমিও পরিবহনে সক্ষম।
আরো আরো আরো কত কী!
বিকেলে চায়ের কাপ কিংবা কোল্ড ড্রিঙ্কসের বোতল মেপে নেয় সারা দিনের কাজের হিসেব।
দিনের শেষে সন্ধ্যায় কাজ সেরে হোস্টেল ফিরে আবার মেতে যাওয়া গল্প আড্ডায়।
তারপর ঘুমের দেশে স্বপ্ন রেশে হারিয়ে যাওয়া।
আজ যা হয়নি, কাল তা পারবো,
পারতেই হবে।

সপ্তাহান্তে একটু নিজেদের মতো করে খাওয়া, ঘোরা।
বুঝিনি বা বুঝতে পারিনি কেটে গেছে ওতগুলো বছর।
হারিয়ে ফেলেছি ছাত্রজীবন নামক ছত্রছায়া।
আজ আর চাইনা বড়ো হতে,
ভালো ছিল কোনো ছায়ায় থেকে যাওয়া।
ছোটো নিজেকে নিজের মতো করে পাওয়া।
ভালো থেকো আই ও পি,
ভালো থেকো বন্ধু সকল।
ভালো তো থাকতেই হবে।
ভালো থাকাই জীবন।
আর জীবনের তরেই জীবন।

A Poem

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ନୁଆ ସକାଳ ଆସିବ କାହୁଁ

ଦେଖ ବୁଡି ବୁଡି ଯାଏ ରବି ।

ପଶ୍ଚିମ ଆକାଶ ପାଟଳେ ରଞ୍ଜିତ

କେଡେ ମନଲୋଭା ଛବି ॥ [୧]

ନଭେ ଗେଣ୍ଡାଳିଆ ଯାଏ ଉଡି ।

ଲୋହିତ ମିଶ୍ରିତ ଧବଳ ପକ୍ଷକୁ

ଆକାଶ ରେ ଝାଡି ଝାଡି ॥ [୨]

ପୁଣି କେତେ ନାନା ଜାତି ପକ୍ଷୀ ।

କିଚିରି ମିଚିରି ଶବଦ କରିଣ

ନିଜ ବସା ଅଭିମୁଖୀ ॥ [୩]

ନଦୀ କୁଳୁ କୁଳୁ ବହି ଯାଏ ।

ସ୍ୱଚ୍ଛ ଜଳରାଶି ସିନ୍ଦୁର ନାଇଛି

ପ୍ରଭାକର ରଙ୍ଗେ ହାଏ ॥ [୪]

ଦେଖ ଘର ମୁହାଁ ଗୋରୁ ପଲ ।

ଗୋଧୂଳି ବେଳାରେ ଗୋଧୂଳି ଉଡେଇ

ସାଜିଛନ୍ତି ସିଏ ମଲ୍ଲ ॥ [୫]

ଏଣେ ପୋଖରୀ ତୁଠକୁ ଦେଖ ।

ଚଷା ଭାଇ ଏଠି ଲଙ୍ଗଳ ଧୋଉଛି

ଦିଶଇ ତା ଥକ୍କା ମୁଖ ॥ [୬]

ତୁଠେ ଗ୍ରାମ ବଧୂ ବସି ଥାଏ ।

ବାସନ ପଖାଳେ ମୁରୁକିବି ହସେ

ମାନେ କିଛି ଭାବୁ ଥାଏ ॥ [୭]

ଗଛେ ପତର ଲାଜେଇ ଯାଏ ।

ଚାନ୍ଦକୁ ସତେକି ଦେଢଶୁର ମଣି

ରାତି ଓଢଣା କୁ ଦିଏ ॥ [୮]

ଏଣେ ସଞ୍ଜା ଉଭା ହେଲା ଆସି ।

ନବ ଗ୍ରାମ ବଧୂ ସଞ୍ଜ ଦୀପ ଦିଏ

ଶଙ୍ଖ ଧ୍ବନୀ ଅସେ ଭାସି ॥ [୯]

ଦେଖି ଦିବାକର ଲୁଚିଗଲେ ।

ଦିବା କୋଳାହଳ ନିସ୍ତବ୍ଧ ହୋଇଛି

ରାହୁ ସତେ ଗ୍ରାସୀ ଗଲେ ॥ [୧୦]

ଭାବେ ଏହି କ୍ଷଣ ରହି ଯାଉ ।

ନିଶବ୍ଦ ରଜନୀ ଉତ୍ତର ଦେଉଛି

ସକଳ ଆସିବ କାହୁଁ

ନୁଆ ସକଳ ଆସିବ କାହୁଁ ॥ [୧୧]

The Night

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ରାତି

ରାତି ଏକ ରମ୍ୟ ଅଟ୍ଟହାସ
କିଟିମିଟି ତିମିରେ କେଳି ରଚେ
ତଟିନୀର ଉଷ୍ଣସ୍ରୋତ ମଧ୍ୟେ ଢ଼ାଳି ପ୍ରଣୟ ଭଉଁରୀ
ଆବାହନ କରେ ଉଚ୍ଛୁଳା ଇନ୍ଦ୍ରିୟକୁ ଜାବୁଡ଼ି
ଛାୟାଚ୍ଛନ୍ନ ଦରଫୁଟା କୁମୁଦକୁ ସଜାଇ
ଉର୍ମିଳା ପ୍ରୀତିସମ କାମନା ଗଣ୍ଡରେ ନାଉରି,
ତେବେ ପୂର୍ଣ୍ଣିମାରେ ପ୍ରହେଳିକା ପାଲଟେ ଇନ୍ଦୁ
ଅସରନ୍ତି ଆଶାର ସଉଧ ସଉଦା ଲେଉଟେ
ତନୁରୁ ସ୍ୱେଦାକ୍ତ ସୁଗନ୍ଧର ତୃଷ୍ଣା ଉତୁରେ
ସ୍ମୃତିର ଶୃଙ୍ଗାର ପ୍ରଶମିତ ହୁଏ ଗୋ,
ଆର୍ଦ୍ର ଶିହରଣ ପୁନଶ୍ଚ ବ୍ୟାପିବ
ବୋଧେ ଗରଜିଲେ
ମିଳନର ମଉସୁମୀ ବର୍ଷାବିନ୍ଦୁ ।

ରାତି ଏକ ପୃଥୁଳ ରମଣୀ
ଯୌବନରେ ସେ ଢାଙ୍କେ ଅଙ୍ଗସୌଷ୍ଠବ
ଜାବୁଡ଼ି ଶିଶିର ବଳୟର ମଇଳା ଚାଦର
ମାତ୍ର ଅସହାୟ ପାଲଟେ
କାମୋତ୍ତେଜକ ଗଣ୍ଠି ଦୃଶ୍ୟମାନ ହୁଏ
ପହଞ୍ଚିଲେ ଶିରିଶିରି ଦୁଲୁକାଏ ହେମାଳ ସମୀର,
ସୁଯୋଗ କି ହୁଏ ହାତଛଡ଼ା
ନିର୍ଜନତାର ଆଶ୍ଳେଷ ଭିତରେ
ଚଗଲା ଯୁବ କବି ଉପମା ଦେଇ
ସାଦା କାଗଜର ପୃଷ୍ଠଭୂମିରେ
ଫର୍ଦ୍ଦ ଫର୍ଦ୍ଦ ଶ୍ଳୀଳ ଅଶ୍ଳୀଳ ଶବ୍ଦ ମଣ୍ଡିତ କରେ
ଆଦିରସ ଭରା ଲେଖନୀ ମୂନରେ ।

ରାତି ଏକ ବିଦଗ୍ଧ ପାଠକ
ସଂଜ ପରେ ବସ୍ତାନି ମେଲାଏ ଭୀତତ୍ରସ୍ତ ମୁଦ୍ରାରେ,
ରୋମାଞ୍ଚିତ ଧାଡ଼ିସବୁ ଉଦରକୁ ଢୋକି ନିଏ
କଳ୍ପନାରେ ସୁଷମା ପ୍ରତିମାର ଗୁଣ ସୁମରି
ମୁନ୍ଦାଏ ଚେତନାର ଚୂନା ଚୂନା ବର୍ଣ୍ଣକୁ
ପରଖି ବିବେକର ଧୂମ୍ରଯୁକ୍ତ ସୂକ୍ଷ୍ମ ପରଦାରେ
ସାଇତେ କବିତା ଗ୍ରନ୍ଥକୁ ନିଷିଦ୍ଧ କୃଷ୍ଣପକ୍ଷ ଅନ୍ଧକାରେ,
ବେଳେବେଳେ ଧୂସରିଆ ଚରିତ୍ରରେ
ନିଜକୁ ଆବିଷ୍କାର କରେ
ପୁଣି କଳାପାହାଡ଼ର ସାଞ୍ଜୁକୁ ଆଦରି
କାରୁଣ୍ୟର କୋଣାର୍କକୁ ଭୂମିରେ ଲୋଟାଏ
ଝାଉଁଳା ଇତିହାସ ବିଧବା ହୁଏ ଗୋ
ପ୍ରାୟଶ୍ଚିତ ପରିକ୍ରମା ସେ କାଳେ କରିବ,
ଗୌରବର କାହାଣୀ ପୁନର୍ବାର ଦୋହରାଇ
ପାଠକୀୟ ଧର୍ମ ଓଠରେ ଫୁଟାଇ
ଅଭିଧାନ ଖୋଲି ଚଞ୍ଚଳ ପିଣ୍ଡରେ ।

The quote "What can be explained is not poetry" is attributed to John Butler Yeats, the Irish artist. But here, the poet is neither J. B. Yeats nor the artist, so perhaps, ironically, a little explanation may be warranted. In this evocative piece, *Night* transcends its temporal boundaries to become an existential canvas where human desire, artistic creation, and historical consciousness collide. The poem weaves a triadic evolution of the soul's nocturnal journey, moving from the raw immediacy of the flesh to the contemplative depths of memory and heritage.

The sensory awakening:

Initially, night manifests as a realm of primal immersion. It is not merely a backdrop for darkness, but a tactile experience where boundaries seem to dissolve. Through the metaphors of warm river currents, whirlpools of affection, and the visceral scent of sweat, the poem frames human intimacy as a force of nature. Nonetheless, this passion is not static; under the quiet scrutiny of the full moon, wild desire mellows into memory. The abiding anticipation of reunion feels as inevitable as monsoon rain, capturing the duality of passion: its capacity to consume and its power to soothe.

The aesthetic impulse:

As the narrative unfolds, night transforms into a muse personified as a figure whose hidden grace is laid bare by a sudden, cool breeze. In this quiet solitude, the poet finds a sanctuary for creation. Guided by Aadi Rasa (the fundamental aesthetic), the act of writing becomes an act of uninhibited liberation. On blank pages, the conventional divide between the sanctified and the profane, the modest (ଶ୍ଳୀଳ) and the obscene (ଅଶ୍ଳୀଳ), vanishes. The creation is presented as a natural impulse, where raw passion is refined into expression.

The philosophical reckoning: In its final movement, the tone turns inward, elevating the night to a discerning reader who sifts through the fragmented layers of conscience. Here, the personal longing intersects with collective cultural memory. By invoking the tragic imagery of Kalapahada and the fallen grandeur of Konark, the poet confronts themes of destruction, loss, and a withered history (ଝାଉଁଳା ଇତିହାସ). Darkness becomes both a sanctuary for forbidden guilt (ନିଷିଦ୍ଧ କୃଷ୍ଣପକ୍ଷ) and a space for quiet atonement.

Ultimately, the poem offers a profound philosophical reflection: night is the mirror of the human condition. It leads us through the heat of desire, into the freedom of creative expression, and finally to a quiet reckoning with history and identity, where the restless heart continuously searches for personality.

Bacteria: A Microscopic World of Sensing, Motion, and Survival

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Introduction: Life has many mysterious ways of working. Some of the most remarkable examples are hidden at a scale far too small for our eyes to see.

Imagine yourself in the early 1600s. You watch food spoil over time, but you have no idea why. You may notice changes in its colour, smell, or texture, yet the cause remains invisible. At that time, it was difficult even to imagine that living organisms could exist beyond the limits of human vision.

Over the following centuries, advances in microscopy gradually opened this hidden world. In 1676, Antoni van Leeuwenhoek observed tiny living organisms using microscopes that he constructed himself. While studying samples of water, he saw numerous microscopic organisms moving around and referred to them as "animalcules", meaning little animals. Today, we know that many of the organisms he observed belonged to the microbial world, including bacteria.[1]

Bacteria are single-celled organisms (see Fig. 9 for an electron micrograph of *E. coli*). Most bacteria are prokaryotic cells, meaning that their genetic material is not enclosed within a membrane-bound nucleus. Bacterial cells are typically a few micrometres in size, although their dimensions vary considerably between species. They are remarkably diverse and occupy almost every environment on Earth. Some are beneficial, some are harmless, and others can cause disease. For example, species of *Lactobacillus* are important in food fermentation and can contribute to the human microbiome, while pathogenic bacteria such as some strains of *Escherichia coli* and *Salmonella* can cause foodborne illness.

Compared with complex multicellular organisms such as humans and animals, bacteria have relatively simple cellular architectures. They lack membrane-bound organelles such as a nucleus and mitochondria, and they do not require the elaborate intracellular infrastructure found in larger eukaryotic cells. Yet this apparent simplicity is deceptive. A single bacterial cell contains a remarkably sophisticated molecular machinery that allows it to sense its surroundings, acquire nutrients, move, reproduce, and adapt to changing conditions.

For a long time, our understanding of these microscopic processes was limited by the capabilities of microscopy. The development of modern fluorescence microscopy, together with genetically encoded fluorescent proteins and other molecular labelling techniques, has made it possible to observe bacterial structures and processes with unprecedented detail. These advances have opened a window into the dynamic processes occurring inside living bacterial cells.

[1] A single bacterial cell is called a bacterium; bacteria is the plural.

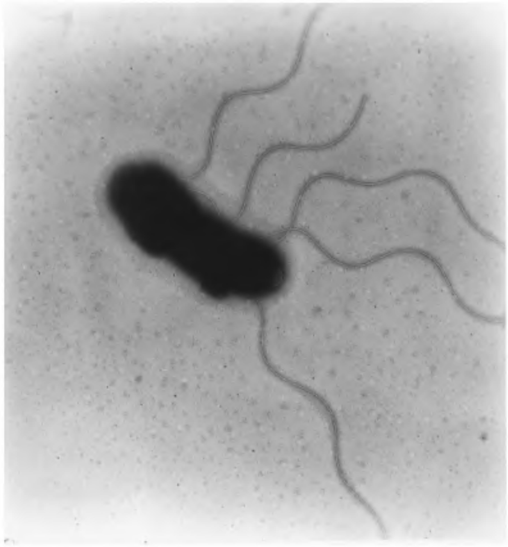

Figure 9: Electron micrograph of *E. coli*. The cell body is only a few micrometres in size, while the flagella are much thinner. The picture is adapted from Ref. [2].

With the development of new experimental technologies, scientists began to ask fundamental questions: How does a bacterium sense its surroundings? How does it move? How does it find nutrients? How does it reproduce? How does it adapt and evolve? And what happens when millions of these tiny organisms interact with one another?

These questions bring together biology, chemistry, ecology, evolution, and physics. In this article, we will look at bacteria from several of these complementary perspectives.

A Bacterium: A Complete World in One Cell

Before thinking about a collection of bacteria, it is useful to first look at a single cell. Although a bacterium is only a few micrometres across, it contains a sophisticated molecular machinery capable of carrying out the processes needed for life.

Sensing the Environment

A bacterium is not simply a passive object drifting through its surroundings. It can detect changes in its environment and respond to them.

The signals it encounters can be physical, such as changes in temperature or mechanical conditions; chemical, such as nutrients or toxic substances; or biological, such as signals produced by other cells. The general logic of cellular signalling can be thought of as a sequence of reception, transduction, and response.

In reception, a signal is detected by a receptor. During transduction, this information is converted into a molecular signal and passed through a chain of biochemical interactions. Finally, the cell produces a response, for example by changing the expression of particular genes.

One example is the response of *E. coli* to low phosphate concentrations through the PhoR/PhoB regulatory system.

When phosphate becomes scarce, the membrane-associated sensor PhoR becomes activated and phosphorylates PhoB. Activated PhoB then regulates the expression of genes involved in phosphate acquisition, helping the bacterium survive under phosphate-limited conditions.

The Swimmer

Sensing the environment is useful only if the bacterium can respond. One important response is movement.

Many bacteria swim using structures called flagella. A bacterial flagellum is a long filament made primarily of the protein flagellin and is driven by a rotary molecular motor embedded in the cell envelope. The motor can rotate at hundreds of revolutions per second, turning the flagellum into a microscopic propeller.

In *E. coli*, several flagella can work together. When the motors rotate in one direction, the filaments form a bundle and propel the cell forward. A change in motor rotation can cause the bundle to break apart, allowing the cell to reorient. Repeated cycles of swimming and reorientation allow the bacterium to explore its environment and, through biased changes in its motion, move preferentially toward favourable conditions. The motion of a bacterium can also be described using a simple mathematical model known as a *run-and-tumble particle* (RTP). In two dimensions, the position of the bacterium can be written as

$$\dot{\mathrm{r}}(t) = v_0 \mathrm{u}(t) + \eta(t), \tag{35}$$

where v_0 is the swimming speed and

$$\mathrm{u}(t) = (\cos\theta(t), \sin\theta(t)) \tag{36}$$

denotes the instantaneous direction of motion. During a *run*, the bacterium moves approximately in a straight line with speed v_0. After a random time, it undergoes a *tumble*, during which its direction changes. The sequence of runs and tumbles therefore produces a persistent but random trajectory.

Mathematically, tumbles can be represented as a Poisson process with rate α. At a tumble, the orientation changes according to

$$\theta(t^+) = \theta(t^-) + \Delta\theta, \tag{37}$$

where $\Delta\theta$ is a randomly chosen change in orientation. Thus, the bacterium retains its direction for a typical run time

$$\tau_{\mathrm{run}} = \frac{1}{\alpha}, \tag{38}$$

before reorienting and beginning a new run.

A typical two-dimensional run-and-tumble trajectory therefore consists of approximately straight segments connected by sudden changes in direction. Despite the simplicity of this description, it captures an important feature of bacterial swimming: persistent motion interrupted by random reorientation.

A trajectory generated from this model is shown schematically in Fig. 11, together with an experimental trajectory of *E. coli*.

Evolution: Surviving a Changing World

The environment is rarely constant. Temperature changes, nutrients become scarce, toxins appear, and predators or viruses may arrive. To survive, bacteria must be able to adapt over

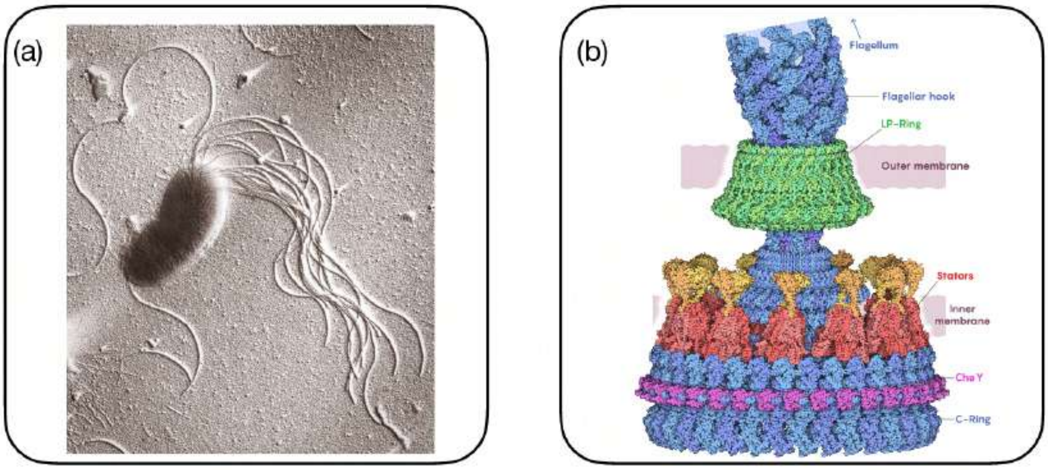

Figure 10: (a) Transmission electron microscopy image showing a cluster of flagella used by *Pseudomonas fluorescens* for locomotion. (b) Schematic illustration of bacterial flagella inspired by structural studies using cryo-electron microscopy. The images are adapted from material presented by *Quanta Magazine*.

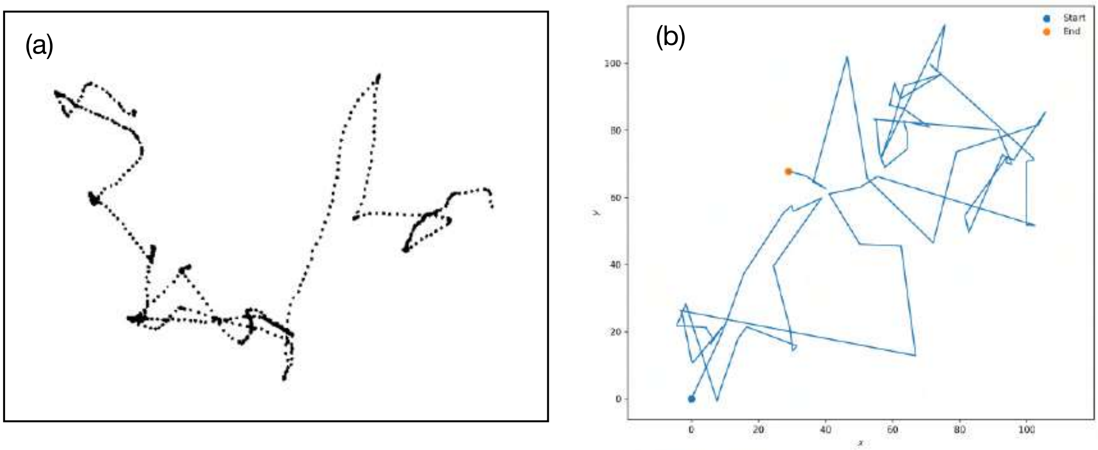

Figure 11: (a) Experimental trajectory of a single *E. coli* cell and (b) a representative trajectory of an active-particle model. The experimental cell was tracked in Adler's motility medium at $32°C$ for 29.5 seconds, with the trajectory digitized at 12.6 frames per second. The trajectory contained 26 runs and tumbles; the longest run lasted 3.6 seconds and the mean swimming speed was approximately $21.2\ \mu m/s$. Panel (a) is adapted from Ref. [2].

generations.

One of the most important mechanisms underlying long-term adaptation is random genetic mutation. Mutations can be neutral, harmful, or occasionally beneficial. If a beneficial mutation gives a bacterium an advantage in a particular environment, its descendants may become more abundant.

A classic demonstration of the random nature of mutation was provided by Salvador Luria and Max Delbruck in 1943. They grew populations of *E. coli* independently and then exposed them to a virus that killed susceptible bacteria. The number of surviving colonies varied greatly between cultures.

This large variation is difficult to explain if resistance appears only after exposure to the virus. Instead, it is naturally explained if mutations arise randomly during growth, before the virus is introduced. A rare resistance mutation occurring early in one culture can be inherited by many descendants, producing a large resistant population, whereas the same mutation occurring late produces far fewer resistant descendants.

This experiment became an important piece of evidence for the idea that mutations arise randomly and are subsequently selected by the environment, rather than being deliberately produced because an organism "needs" them.

Reproduction: How Does a Cell Know When to Divide?

Like all living organisms, bacteria must reproduce to continue their lineage. Many bacteria reproduce through binary fission. Before division, the cell replicates its DNA, grows, and reorganizes its internal machinery before separating into two daughter cells.

But this raises a deceptively simple question: how does a bacterium know when it is ready to divide?

Several ideas have been proposed to explain bacterial cell-size control. Three influential models are the *timer*, *sizer*, and *adder* models.

In the timer model, a cell waits for a characteristic amount of time after birth before dividing. In the sizer model, the cell monitors its size and divides after reaching a characteristic size. In the adder model, the cell adds approximately a fixed amount of volume between birth and division, largely independent of its size at birth.

The first two ideas are intuitive, but each has difficulties when confronted with the observed variability of cell sizes. The adder model provides a particularly simple mechanism for stabilizing cell size: a small cell tends to add roughly the same amount of volume as a large cell before division. Consequently, the sizes of daughter cells tend to fluctuate around a characteristic value rather than becoming progressively smaller or larger.

Experiments on bacterial growth have provided strong evidence supporting adder-like behaviour in several bacterial systems. A representative result is

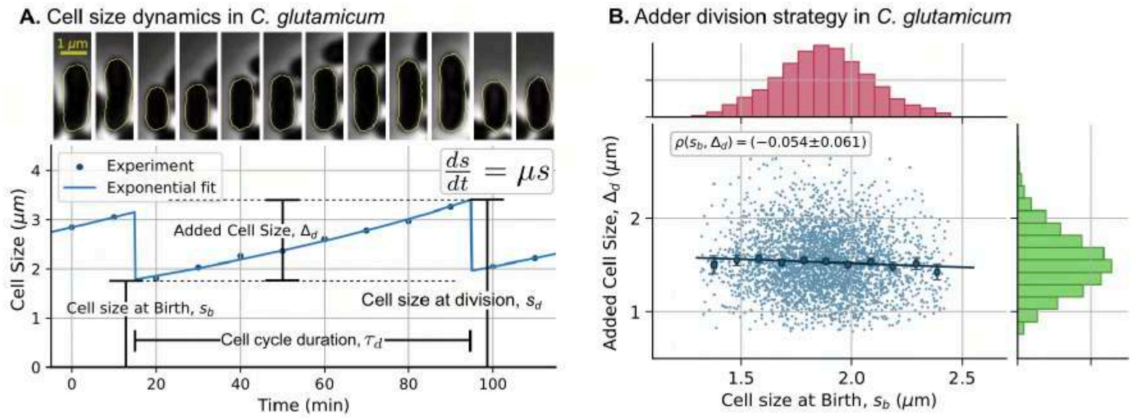

Figure 12: Cell-size homeostasis in *C. glutamicum* through the adder mechanism. (A) Top: time-lapse images of a *C. glutamicum* cell undergoing division, with one of the newborn cells randomly chosen for size tracking. Bottom: cell size, quantified by cell length, as a function of time. The solid line represents an exponential fit to the growth. The key cell-cycle variables are indicated on the plot. Here, s_d is the cell size at division and s_b is the cell size at birth. (B) The data reveal adder-like cell-size control, where $\Delta_d = s_d - s_b$ is uncorrelated to s_b across *C. glutamicum* cell cycles. The picture is adapted from Ref. [3].

shown in Fig. 12.

Collective Dynamics: When Bacteria Act Together

A single bacterium is already a remarkable microscopic machine. But the story becomes even more interesting when thousands or millions of bacteria interact.

Bacterial populations can exhibit collective behaviours such as swarming, coordinated motion, enhanced transport, and pattern formation. They can also form biofilms: communities in which bacteria live within a protective matrix containing extracellular polymeric substances, including polysaccharides, proteins, and other biomolecules.

Swarming is particularly striking (see Fig. 13 for an example of collective motion in *E. coli*). Instead of moving independently, bacteria can organize their motion so that groups of cells travel coherently, producing large-scale patterns that emerge from local interactions.

One way to model such collective motion is to begin with the mathematical description of a single swimmer and add interactions between neighbouring bacteria. Schematically,

$$\dot{\mathrm{r}}_i = v_0 \mathrm{u}_i + \mu \mathrm{F}_i + \eta_i, \qquad (39)$$

where the interaction force F_i contains contributions from neighbouring bacteria. An alignment interaction can be introduced to make the direction of one bacterium tend to align with the directions of nearby bacteria.

For example, one may write

$$\dot{\theta}_i = \text{alignment with neighbours} + \text{noise}, \qquad (40)$$

where the strength and spatial range of the alignment determine how strongly bacteria influence one another.

Remarkably, relatively simple models of this kind can reproduce qualitative features of collective bacterial motion.

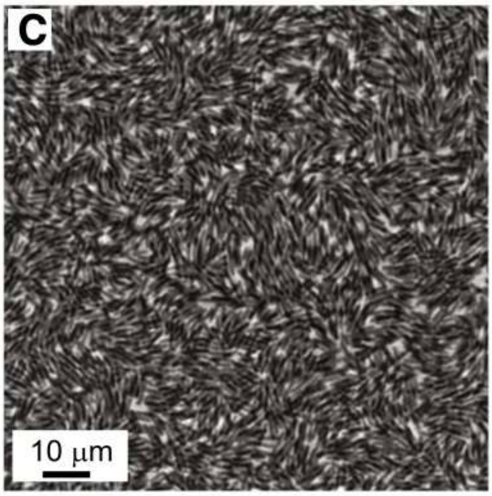

Figure 13: Collective motion of *E. coli* bacteria. The picture is adapted from Ref. [1].

Such models also provide a bridge between the microscopic dynamics of individual bacteria and the large-scale patterns observed in bacterial populations.

A Microscopic World Still Full of Questions

The examples above represent only a small part of the bacterial world. Inside a single cell, molecular machines continuously transport materials, store and replicate genetic information, produce energy, maintain the cell envelope, communicate with neighbouring cells, and respond to changes in the environment.

What makes bacteria especially fascinating is that all of this happens within a microscopic space, using physical and chemical processes that operate far below the scale accessible to our everyday experience.

We can therefore look at bacteria in several complementary ways. Biology tells us about their molecular machinery and cellular functions. Chemistry describes the reactions that make those functions possible. Ecology asks how bacteria interact with their environment and with one another. Evolution explains how populations change over generations. Physics provides mathematical tools for understanding their motion, fluctuations, interactions, and collective behaviour.

A bacterium may be only a few micrometres across, but within that tiny space lies an entire world of sensing, motion, reproduction, adaptation, and collective behaviour. And despite centuries of discovery, much of that world remains hidden.

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The Man Who Disappeared and the Particle That Might Not

Ettore Majorana vanished without a trace in 1938. Nearly ninety years later, physicists are still chasing the strange particle he left behind - one that may be its own opposite.

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On the night of March 25, 1938, a young Italian physicist named Ettore Majorana boarded a ferry from Palermo to Naples - and was never seen again. No body was found. No confirmed sighting ever surfaced. All that remained were a few unsettling letters, one hinting he might drown himself, another written the next day claiming he had changed his mind. Enrico Fermi, who worked beside him, once said Majorana's mind belonged in the same league as Galileo's and Newton's. So why did such a brilliant, quiet, brooding scientist disappear so completely?

Figure 14: March 25, 1938: the Palermo-Naples ferry crossing after which Ettore Majorana was never seen again.

We may never know. But Majorana's true legacy isn't the mystery of his vanishing - it's an idea so strange that physicists are still chasing it nearly ninety years later.

In 1937, the year before he disappeared, Majorana published a paper proposing something wild: what if certain particles could be their own antiparticles?

Every particle you've probably heard of - electrons, protons, quarks has an antimatter twin: same mass, opposite charge. When a particle meets its antiparticle, the two annihilate in a burst of energy. Electrons and their antimatter counterparts, positrons, are the classic example: distinct, opposite, doomed to destroy each other on contact.

Picture a coin that is heads and tails on the very same side.

Majorana asked a different question: what if a particle had no charge at all, and simply *was* its own antiparticle? Not merely similar to it - literally itself.

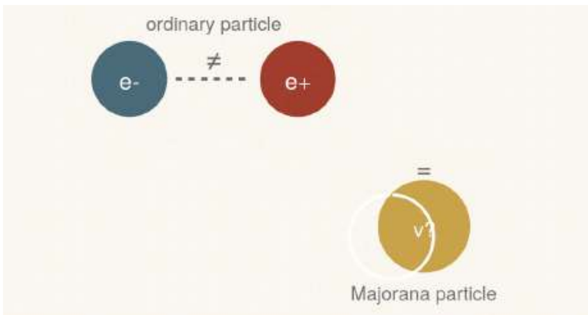


Figure 15: Ordinary particles (like the electron) have a distinct antiparticle. Majorana proposed a class of particles - possibly the neutrino - that are identical to their own antiparticle.

This wasn't just clever math on a chalkboard. Majorana's equations described real, testable physics - a class of particles now called Majorana fermions. For decades they lived

mostly in theory papers. Then neutrinos entered the picture. These ghostly particles barely interact with anything - trillions pass harmlessly through your body every second - and they carry no electric charge, making them the prime suspect for Majorana's strange particles. If neutrinos really are their own antiparticles, it could help explain one of cosmology's biggest puzzles: why the universe is filled with matter at all, instead of nothing, given that matter and antimatter should have annihilated each other completely at the Big Bang.

More recently, Majorana particles have found a second life in a very different arena: quantum computing. Under the right conditions - ultra-cold semiconductor wires paired with superconductors - physicists have spotted something that behaves like a Majorana particle appearing at the edges of a material. It isn't a fundamental particle but a collective ripple of electrons, nicknamed a "Majorana zero mode." These are exciting because they might store quantum information in a way that resists the errors plaguing today's quantum computers.

So the same man who slipped out of history without a trace left behind a particle that refuses to be pinned down as purely matter or purely antimatter. Nearly a century later, labs around the world are still hunting for definitive proof that Majorana particles exist in nature. It is, in its own way, a fitting tribute: the search for a ghost, chasing the ghost of a particle.

My Journey with the Institute of Physics

Prof. Pradip Kumar Sahu
Year of joining - 2004 • Experimental High Energy Physics

The Institute of Physics (IOP), Bhubaneswar, is undoubtedly one of the premier institutions for physics research and education in India. I consider myself extremely fortunate to have had a long and enriching association with IOP-first as a student and later as a faculty member. My journey at the institute has been one of learning, discovery, and continuous intellectual growth. Even after completing my postdoctoral research in Germany, Japan, Italy, and several other places, I returned to IOP with a deep sense of belonging and gratitude. My experiences at IOP have shaped not only my scientific career but also my broader understanding of what it means to be a physicist.

During my student years, I had the rare privilege of interacting with some of the finest physicists and teachers associated with IOP and the wider international physics community. I was fortunate to learn from eminent scientists such as Prof. Asoke Sen, Prof. Jogesh Pati, Prof. R. K. Bhaduri, and many other distinguished researchers. Their knowledge, intellectual curiosity, scientific discipline, and enthusiasm for physics had a profound influence on me. Interacting with such accomplished scientists opened my eyes to the vast and fascinating world of physics. More importantly, it taught me that physics is not merely a collection of equations and theories; it is a way of thinking, questioning, exploring, and understanding nature.

One of the most valuable aspects of my association with IOP was the excellent scientific environment. We had opportunities to learn not only from our teachers and senior scientists but also through interactions with researchers from around the world. Participation in national and international conferences, workshops, seminars, and scientific meetings exposed us to the latest developments in physics and allowed us to interact with some of the leading scientists of our time. These experiences broadened our perspective and gave us the confidence to participate in the international scientific community.

IOP also has several unique facilities that make it an exceptionally friendly place for physics. The availability of a library around the clock has always been particularly valuable for students and researchers. A good library is the heart of any research institution, and having access to scientific literature whenever needed creates an environment in which curiosity and research can flourish. The institute also attracts talented students and young researchers from reputed universities, IITs, and institutions across India. The opportunity to interact with such talented and motivated people is itself a great learning experience. Discussions over a scientific problem, informal conversations, and collaborations often become as important as formal classroom teaching.

My return to IOP as a faculty member was therefore a particularly meaningful chapter of my professional life. I had the good fortune to work with highly talented students and young researchers, and these interactions continued to teach me new things every day. Teaching and research became a two-way process: while I tried to share whatever knowledge and experience I had gained, my students constantly challenged me with new questions, ideas, and perspectives.

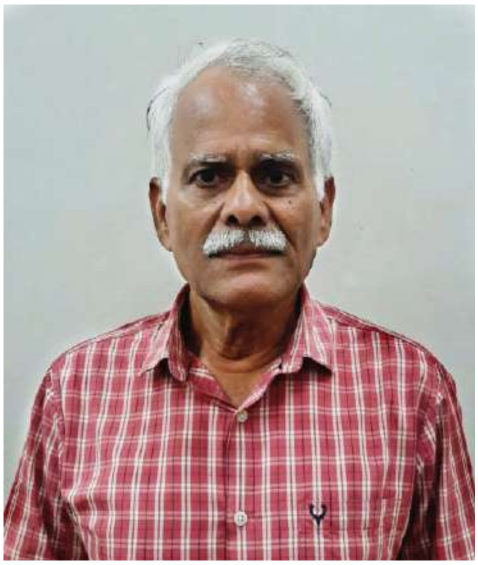
Looking back, I feel deeply grateful to IOP for providing me with an environment in which I could learn, grow, conduct research, teach, and interact with generations of talented physicists. IOP has been much more than an institute for me; it has been an important part of my intellectual and professional journey. The friendships, teachers, students, scientific discussions, and memories associated with the institute will always remain special. I feel truly fortunate to have been both a student and a faculty member at such a wonderful institution and to have experienced, in its fullest sense, the joy of being part of the world of physics.

The Journey

Prof. Prashanta K. Panigrahi
Predoc-1980 batch • Theoretical High Energy Physics

Institute of Physics (IoP) was a beacon to many of us, studying physics in colleges of Odisha. From my bachelors and masters in science days in the 70's (1976-1980), our teachers in Ravenshaw College (presently Ravenshaw University) had, on more than one occasion, narrated to us about this wonderful place, where brilliant minds are carrying out fundamental research. In fact, my favourite teachers Prashant Jena and Laxmidhar Moharana had been frequenting this place in Bhubaneswar, bringing journals and recent publications for us to browse through. Due to their effort, a one-day workshop was held in our college with Prof. T. Pradhan leading the team of faculty to our college for delivering seminars. This had quite an impact on many students, some of whom would eventually join in the doctoral and pre-doctoral program of IoP. Reading and digesting the books from MIR publication, I had fancied myself as a researcher. I ventured to the institute premises with a friend, to discuss with the resident physicists my concepts on harnessing radioactivity as a controlled source of energetic charged particles and another idea of the origin of spin angular momentum.

To my surprise, Prof. Pradhan and Dr. Ansari took me 'seriously', diligently explaining to me using the blackboard the 'rawness' of my ideas. They described concepts like particle flux, scattering cross section as well as spin being an intrinsic property of the particle, owing its origin to relativity. This had a 'cooling' effect on me, making me study more seriously with problem solving as a key component of my education.



As we were finishing MSc in physics, the Institute of Physics became a more familiar 'word' for us, where our super senior, Pramoda K. Mohapatra, had already joined, with the idea of grand unification of physical forces in mind. My classmate Tapaswini Patnaik and I joined IoP for the pre-doctoral program. The rigorous coursework, fond memories of teachers like Profs. Behera, Rao, Pradhan, Padhi, Phatak and Misra, are also juxtaposed with failing for the first time in my life, in the particle physics courses of Profs. Maharana and Khare.

The presence of classmates like R. P. Malik, Tapan Naik, Biswajyoti Dey, Samir Pal, Ravi, Prabhakarudu and Smitha from different parts of India gave the institute a unique flavour, enriched with frequent visits of eminent researchers from India and abroad.

The institute moved from Saheed Nagar to its new abode near the far-off Sainik School, being inaugurated by the then prime minister Indira Gandhi! The visit of the Nobel laureate Abdus Salam, with collaborator Jogesh Pati, made us fall for theoretical particle physics as the field to pursue for higher studies. I was encouraged by Prof. Khare to explore larger horizons, leading me to City College and then University of Rochester for carrying out my doctoral work.

The institute had a close association with nearby Utkal University, with the faculty of the university having access to the excellent library and research preprints. The picnics in nearby scenic places, musical evenings and playing card games used to keep us refreshed. The rigorous coursework, end-semester viva voce and the grand viva at the end of the academic year are still fresh in my mind.

After joining the graduate programs of the City College of the City University of New York and then University of Rochester, I valued my days in IoP much more. I stayed in regular touch with the institute faculty, during their visits to the USA and on my trips back home. In fact, my entry into research through the ABJ anomaly and its connection with spin have been deeply influenced by Profs. Pradhan and Khare. My first paper on path integral derivation of anomaly in bosonic strings was with Prof. J. Moharana, who had a collaboration with my supervisor Ashok Das.

Moving to University of Illinois at Chicago, I rediscovered my association with IoP, through the fundamental contributions of Avinash Khare. This association was going to stay much longer, as during my postdoctoral tenure in University of Montreal our collaboration extended to Chern-Simons field theory. After coming back to India, I have been visiting IoP, on more than one occasion.

All my visits to Bhubaneswar would lead me to the institute, charging me with fresh energy and enthusiasm, being impressed by the highest standard of the academic pursuit and research atmosphere. It is not surprising that this 'tiny' place has gained a foothold in the global domain, with its alumni spread across the world.

Perovskite Solar Cells: A New Chapter in the Solar Energy Story

Dr. Pronoy Nandi
Predoc-2013 batch • Experimental Condensed Matter Physics

For most of us in India, a solar panel means a large, dark-blue or black silicon panel fixed on a rooftop or spread across a solar park. Silicon has earned this position through decades of development and will remain the backbone of photovoltaics for years. Yet a new family of materials metal-halide perovskites is changing what we imagine a solar cell can be. Perovskite solar cells can be thin, lightweight, semi-transparent and flexible. Their performance has improved remarkably fast, taking them from laboratory curiosity to a serious candidate for next-generation solar power. The word perovskite describes a crystal structure rather than one single material. By changing its chemical composition, researchers can tune which wavelengths of sunlight it absorbs. A perovskite absorber can be only a fraction of the thickness of a human hair yet absorb sunlight effectively. Unlike crystalline silicon, which needs high-temperature processing, perovskite layers can potentially be deposited using low-temperature coating or printing methods. This opens possibilities that are difficult with heavy, rigid silicon modules [1-2].

Does that mean perovskite have already defeated silicon? Not quite. The more exciting story is how the two can work together. A silicon cell cannot use every part of sunlight equally efficiently. In a tandem solar cell, a perovskite top cell captures higher-energy light while silicon underneath collects lower-energy light. This “division of labour” allows perovskite-silicon tandems to move beyond the practical efficiency of todays single-junction

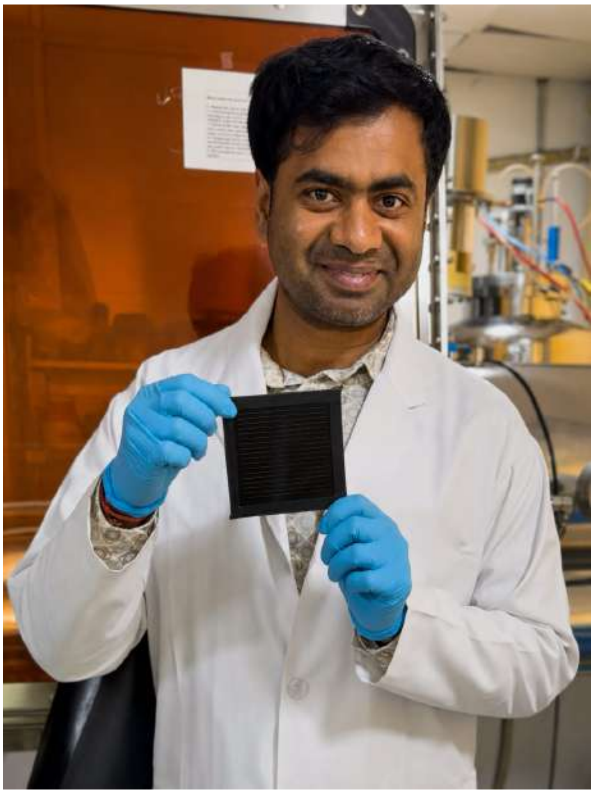


Figure 16: Me with a 10cm × 10 cm Perovskite solar module.

silicon technology [3]. Laboratory tandem cells have crossed the mid-30% efficiency range, and commercial tandem modules have begun reaching customers. All-perovskite tandems, using two perovskite layers with different compositions, offer another route, especially where low weight and flexibility matter [4].

This is where perovskites could change our everyday relationship with solar energy. Imagine the glass facade of an office building producing electricity without looking like a conventional panel. Semi-transparent or coloured perovskite modules could become part of windows, roofs and walls an approach known as building-integrated photovoltaics (BIPV) [5]. For Indian cities, where available land is limited but building area is enormous, such solar skins could be valuable. Agriculture offers another opportunity. In agrivoltaics, crops and solar modules share the same land. Lightweight or partially transparent perovskite modules could allow useful sunlight to reach plants while generating electricity above them. In a country where land must support food, livelihoods and energy, this could improve land productivity, provided crop response, durability, cost and farm operations are carefully considered. At the other end of the power scale are tiny electronic devices. Internet of Things (IoT) sensors used in homes, factories, farms and healthcare often need only small amounts of power. Perovskites can work well under low-intensity and indoor illumination, making them interesting miniature energy harvesters that could reduce dependence on disposable batteries. Their optoelectronic properties are also being explored for photodetection and light-based communication, including systems related to LiFi, where information is transmitted using light rather than radio waves [5].

Perhaps the most futuristic destination is space [1]. Every kilogram launched into orbit costs money, so power per unit weight is crucial. Perovskite devices can be extremely thin and lightweight, and studies show encouraging tolerance to high-energy radiation. Perovskite and perovskite-based tandem cells are therefore being investigated for satellites, high-altitude platforms and future space missions. However, vacuum, ultraviolet radiation and severe temperature cycling create challenges very different from those on Earth.

This technology still has important weaknesses. Perovskites contain mobile ions [6]. Under light, heat or an electric field, these ions can migrate, changing interfaces and accelerating performance loss. Moisture and oxygen can attack many compositions, while prolonged illumination and high temperature can trigger further degradation. Scaling a tiny laboratory cell into square-metre modules without defects is another challenge. Encapsulation must keep water out for years, manufacturing must be reproducible, and lead-containing devices require responsible containment and recycling.

Still, commercialization is no longer a distant promise. Oxford PV announced the first commercial shipment of perovskite-silicon tandem modules in 2024 [1]. In China, megawatt-scale perovskite demonstrations have been connected to the grid, including 1 MW projects, while companies have commissioned manufacturing lines at hundreds-of-megawatts to gigawatt scale. These numbers remain tiny beside the enormous silicon industry, so it is premature to call perovskite a mass-market replacement. But the transition from centimetre-sized research cells to factories, rooftops and field installations has clearly begun.

For India, the question should not simply be whether perovskite will replace silicon. A better question is: where can it do things that silicon cannot do easily? High-efficiency tandems can generate more electricity from limited land; lightweight modules can use roofs that cannot carry heavy panels; semi-transparent devices can turn buildings and greenhouses into power generators; and flexible cells may create entirely new products. The next decade will decide how many of these possibilities survive the demanding tests of cost, lifetime and scale. If they do, the solar panel of the future may no longer look like a panel at all: it may be a window, a wall, a farm canopy, a sensor, or even the skin of a spacecraft.

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When Diffusion Creates Patterns

The Physics of Turing Instability

Raj Upadhyay
Predoc-2022 batch • Theoretical Soft Matter Physics

One of the fascinating questions in physics is how a system that begins in a nearly uniform state can spontaneously develop spatial structure. In many physical systems, diffusion is associated with smoothing out spatial differences: particles move from regions of high concentration to regions of low concentration, tending to make the system more homogeneous. However, in 1952, Alan Turing(Same Alan Turing who gave idea of Turing Machines) showed that when diffusion is coupled with chemical reactions, it can have a counterintuitive effect. Under appropriate conditions, diffusion can destabilize an otherwise stable homogeneous state and lead to the spontaneous formation of spatial patterns. This idea, introduced in his work "The Chemical Basis of Morphogenesis", provided an important physical mechanism for understanding how ordered structures can emerge from simple local interactions. The significance of Turing's work extends beyond chemistry and biology, since instability and spontaneous pattern formation are fundamental concepts in physics, appearing in systems ranging from phase transitions and fluid instabilities to active and biological matter such as cell cytoskeleton. The central insight of Turing boils down to essentially 4 key ideas.

- At least two species of reacting chemicals are required for the pattern formation to occur.
- Diffusion of chemicals while reacting can actually be the source of instability on contrary to classical idea that diffusion by itself smooth outs spatial variation in chemical concentration.
- This instability caused by diffusion cause the growth of structures at a particular wavelength.
- Pattern formation in chemical systems will not occur unless there is substantial difference between the diffusion coefficient between the reagents.

A useful example for the visualizing the ideas is the example of Gary Scott reaction diffusion system. It consists of two chemical species which reacts in a non-linear fashion and diffuses in space. Mathematical Equations numerical patterns are given in the website with the barcode. Starting from an almost homogeneous state with a small perturbation, the coupled reaction and diffusion dynamics can amplify certain spatial modes while suppressing others. Depending on the parameters governing the reaction and diffusion processes, the system can develop a variety of structures, including spots, stripes, and other complex spatial patterns. The important point is that these structures are not explicitly prescribed in the initial conditions. Instead, they emerge dynamically as a consequence of the instability of the homogeneous state.

Turing also pointed out that the idea of instability-driven pattern formation can also be extended beyond chemical reaction-diffusion systems. In the works of Justin S Bois, Frank Jülicher, Stephan W Grill, V. Kumar, a related mechanism can be understood through mechanical coupling and feedback. Instead of chemical concentrations being the variables that interact and diffuse, mechanical degrees of freedom are coupled to one another, allowing a local deformation or displacement to influence the surrounding system. This interaction can generate feedback between different parts of the system, and under suitable conditions, the feedback can amplify particular spatial modes. Although such a mechanical system need not be a classical Turing system in the strict mathematical sense, it shares an important conceptual connection with Turing's mechanism: spatial structure can emerge spontaneously when local dynamics are coupled through transport, interaction, and feedback.

What makes Turing idea so powerful is that the complex patterns does not require complex instructions. Simple local interactions combined with spacial coupling and a appropriate instability can be sufficient organized structures. From chemical reaction diffusion systems to mechanically coupled systems, emergence of pattern can therefore be viewed as the manifestation of broader physical principle:under the right conditions, an initially uniform state can become unstable, and the instability itself can provide the mechanism through which structure emerges. The accompanying simulations explore these ideas visually, allowing the development of the instability in Biological and active systems and the emergence of spatial patterns to be followed directly in time.

Institute of Physics: A World of Endless Opportunities

Dr. Sachindra Nath Sarangi
Year of joining - 2013 ● Experimental Condensed Matter Physics

ପଦାର୍ଥ ବିଜ୍ଞାନ ପ୍ରତିଷ୍ଠାନ: ଅସୀମ ସୁଯୋଗର ଅବକାଶ

ଶଚିନ୍ଦ୍ର ନାଥ ଷଡଙ୍ଗୀ

ଜ୍ଞାନର ଦୀପ ଜଳେ ଯେଉଁଠାରେ
ସ୍ୱପ୍ନର ପକ୍ଷୀ ଉଡ଼େ,
ପ୍ରତିଭା ଏଠି ପଥ ଖୋଜି ଖୋଜି
ନୂଆ ଶିଖର ଚଢ଼େ ।

ମୋ ପ୍ରତିଷ୍ଠାନ ଏ ମୋରି ଗର୍ବ
ମୋ ଆଶାର ଆଲୋକ,
ନୀତି ଏଠି କିଛି ପ୍ରଶ୍ନ ଜନ୍ମ ନିଏ,
ଖୋଜେ ଉତ୍ତର ଅନେକ ।

ବିଜ୍ଞାନ ଏଠି ପୁସ୍ତକ ନୁହେଁ
ଜୀବନର ପରିଭାଷା,
ପରୀକ୍ଷାଗାରରେ ନିତି ବିକସଇ
ଆଗାମୀ ଦିନର ଆଶା ।

ଯୁବମନେ ଆଜି ଜ୍ୱଳେ ଯେ ଅଗ୍ନି
ସ୍ୱପ୍ନରେ ଭରେ ପ୍ରାଣ,
ସୁଯୋଗ ମିଳିଲେ ଏଇ ପ୍ରତିଭା ଯେ
ରଚିବ ନୂଆ ସପନ ।

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ସହଯୋଗେ ଏଠି ଗଢ଼ି ଉଠି ଥାଏ
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ଆଜିର ଏକ ଛୋଟ ପଦକ୍ଷେପ
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ଆସ, ଆସ ଆମେ ହାତେ ହାତ ଧରି
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ପରିଚୟ କୁ ଲେଖିବା ।

ମୋ ପ୍ରତିଷ୍ଠାନ : ମୋ ରି ସ୍ୱପ୍ନ
ମୋ ଆସନ୍ତାର ଗୀତ,
ଅସୀମ ସୁଯୋଗ ଏ ଆକାଶ ତଳେ
ସଫଳତାର ପ୍ରତୀକ ।

ଯେଉଁଠି ମିଳେ ସ୍ୱପ୍ନକୁ ପଥ
ପ୍ରତିଭାକୁ ପରିଚୟ
ସେଇ ଅନୁଷ୍ଠାନ ମୋ ଅନୁଷ୍ଠାନ,
ଭବିଷ୍ୟତ ପରାଭୟ ।

My institution is a place of pride, hope, knowledge, and endless opportunities, where the lamp of learning shines brightly and young dreams spread their wings toward new horizons. Here, talent is encouraged to explore, question, discover, and climb new heights. Science is not merely found in books; it becomes a living experience through experiments, research, and innovation. The youthful minds here burn with curiosity and ambition, and with the right opportunities, they can create new knowledge and shape a better tomorrow. Research opens new frontiers, technology creates new paths, and teamwork builds the chariot of success. Every student is given the courage to dream, the freedom to explore, and the opportunity to turn those dreams into reality. A small step taken today can become a giant leap toward a brighter future. Together, let us join hands, welcome a new dawn, share the light of knowledge with the world, and create an identity that fills our institution with lasting pride, purpose, and glory. My institution is a world of dreams, knowledge, and endless opportunities. It gives every student the courage to explore, the freedom to innovate, and the path to success. Here, talent finds recognition, dreams find direction, and young minds prepare to shape a brighter tomorrow with confidence, creativity, and hope.

A Leaf from the Days in Brazil: Tale of two dreams

Prof. Saptarshi Mandal
Year of joining - 2015 • Theoretical Condensed Matter Physics

I did my first postdoctoral stint in Brazil, where I spent two years at two different institutions - one year at each. Looking back, it is difficult to fully express any experience through speech or writing. Experience, in some sense, follows a principle reminiscent of quantum mechanics: whenever we try to "measure" it, only a part of it can be captured. Great authors are perhaps those rare people who can unfold the colors of an experience before the reader with remarkable fidelity.

Here, I would like to share two dreams that became part of my journey with physics. They were almost of opposite polarity, yet perhaps complementary. The first one was experienced while I was asleep, while the second unfolded while I was awake. Together, they raise a deeper question: how does the mind function? Is there any continuity between the conscious, subconscious and perhaps even the super-conscious mind?

I joined my first institution, ICCMP, in Brasília in the first half of February 2009. The initial conditions were quite challenging, but I would like to skip those details and come directly to the first dream.

I spent my first month in a university guest house and then moved to a small kitchenette-style apartment, specially rented for one or two persons. The university was about one and a half kilometers away, within walking distance. Adjacent to our apartment complex, on the opposite side from the university, was a large open playing field, where I used to go every morning for some physical exercise.

One night, around August 2009, I had a strange dream. I was standing in the field, surrounded by several owls. The owls seemed to be communicating with one another. I found the dream quite unusual.

During those initial days, I also had some rather ordinary dreams - for example, I dreamed that I was talking and gossiping with my favorite group of friends from IMSc. That was hardly surprising. I was missing them a lot, and while my conscious mind was busy adjusting to a completely new environment and way of life, my subconscious mind was perhaps craving the familiar Bengali "adda".

But the dream about the owls was different. Curious, I searched Google for possible interpretations. As expected, I found many different explanations. One of them suggested that seeing owls might symbolize encountering people with great wisdom and insight.

Owls are nocturnal animals: they sleep during the day and remain awake at night. There is an interesting parallel here with the idea of wisdom. To gain wisdom, perhaps one needs to remain attentive to questions that ordinary minds do not necessarily find interesting, while remaining indifferent to some of the things that occupy ordinary minds.

Interestingly, a similar idea appears in the Bhagavad Gita. In Chapter 2, verse 69, Krishna says:

> *"What is night for all beings is the time of wakefulness for the disciplined one; and what is the time of wakefulness for ordinary beings is night for the sage who sees."*

After looking at several possible interpretations on Google, I convinced myself that perhaps I was going to meet some wise people. It seemed like a reasonable interpretation of the dream.

Of course, after a few days I forgot all about it. Life was quite challenging, and I was busy balancing the various chores of everyday life in a new country.

Then, a couple of weeks later, I came across an advertisement on the website of ICCMP for a conference featuring several distinguished scientists, including a Nobel laureate. I was quite startled. Could my strange dream actually be materializing?

Indeed, during that conference I met several remarkable physicists. I met Prof. S. R. Salinas and had the opportunity to speak with Prof. E. H. Lieb. I had studied Lieb's theorem in connection with the Kitaev model and had spent more than six months trying to extend the idea to a three-dimensional Kitaev model, though I was ultimately unsuccessful.

I also met Prof. F. D. M. Haldane, who was visiting the institute around that time, although he was not part of the conference. I remember taking a photograph with him and another professor. In fact, the other professor had asked me to take their photograph so that he could keep it as a memory. I also remember that Prof. G. Baskaran was visiting the institute at that time. On several occasions he told me, Haldane is very deep. At that time, I did not quite understand what he meant. I began to appreciate the profound nature of that remark only years later, when Haldane received the Nobel Prize in Physics in 2016.

Finally, I met G. Jackeli and G. Khaliullin, who had just published their groundbreaking work on the material realization of the Kitaev model. For someone working on Kitaev physics at that time, meeting these people was extraordinary.

I also keenly observed Prof. David Gross, as he was the first Nobel laureate I had ever seen in person. One particular incident left a lasting impression on me. In one of the conference sessions, the audience was very small because the conference was nearing its end and the speaker was relatively unknown. Yet Prof. Gross was sitting there, listening with full attention and carefully engaging with the speaker's arguments. That stayed with me. I have noticed the same quality in several other accomplished scientists: they do not judge a book by its cover.

Indeed, I thought, my dream had come true.

The Other Side of the Journey:

The Brazil experience will probably never be repeated, and I do not know whether I will ever have the opportunity to visit Brazil again. But before ending this story, I would like to recall another part of the experience-the academic journey and the lesson I learned from it.

The day before I left for Brazil, I met Shankar at IMSc, as I had started my journey from Chennai. I do not remember whether the meeting was planned or accidental; I think it was accidental. I remember that it was around 10 p.m. I was going to the office one last time, while Shankar was returning from his office. We met at the entrance.

After some discussion, he hugged me and said, "I wish you perform well, because whatever you do during your PhD, people think it is because of your guide."

That sentence stayed with me.

Unfortunately, within a month of arriving in Brazil, my postdoctoral mentor and I discovered that the project we were supposed to work on had already appeared on the arXiv. We were suddenly left wondering what to do next.

I then decided to learn Functional Renormalization Group (FRG), an area in which my mentor was an expert and in which the director of the center had also been working for a long time. This decision was made around April or May 2009.

Meanwhile, the director decided to establish a new center in Natal, more than 2,000 km away from Brasília, and move the activities of the existing center there. This created another unexpected challenge for me. I now had to relocate from Brasília to Natal, find a new house and somehow manage everything while the new center itself was non-existent and many of the basic support facilities were not yet available.

As a foreigner, it was a particularly difficult situation.

When the administrative manager came to know about my situation, he humorously declared, "Saptarshi is the bravest person among us! He wishes to reach Natal before we do!"

Brazilians are very humorous people. Sometimes, with one funny comment, they can take away much of your worry.

Fortunately, I came to know that some other postdocs, Humberto from Brazil and Daniel from Peru, were also moving to Natal. We initially stayed in a hotel for a week or two and searched for an apartment ourselves. I can never forget the help I received from Humberto, with whom I eventually shared a very nice apartment about 6 - 7 kilometers from UFRN in which the institute started its activity as it did not have its own building. After few months it relocated to a rented house nearby.

Slowly, I began to catch up with my studies. But I soon realized that the problem I was working on - the Anderson impurity problem - had already been extensively studied, and it would be difficult to obtain anything substantially new from it. The director himself suggested that I move to another problem.

I moved to heavy-fermion systems and began applying FRG to them. Around that time, an interesting experimental work on a heavy-fermion system involving point-contact spectroscopy appeared. The discussion around us suggested that we should try to understand the experimental features theoretically, particularly the Fano resonance associated with the heavy-fermion state.

That brought another challenge.

The problem required a formalism of transport and, therefore, a knowledge of non-equilibrium Green's functions - the Keldysh formalism. I started learning the method with another PhD student, Thiago. After about six months, we obtained some preliminary results.

And then, once again, we discovered that A. V. Balatsky and his co-authors had already published a closely related theoretical treatment in *Physical Review Letters*: P. Wölfle, Y. Dubi, and A. V. Balatsky, "Tunneling into Clean Heavy Fermion Compounds: Origin of the Fano Line Shape," Physical Review Letters 105, 246401 (2010).

My dream was shattered for the second time.

I was quite disappointed. During the last three or four months of my stay in Brazil, I began studying the physics of high-temperature superconductors and looking for my next postdoctoral position.

Fortunately, I received an offer from my old collaborator and mentor, Prof. Krishnendu Sengupta. I moved on, once again starting afresh and trying to put together the missing pieces of my academic journey.

Looking only at the publication record, one might conclude that my two years in Brazil were not particularly productive. Today, however, I see those two years very differently.

Brazil gave me a vast exposure to strongly correlated physics and to a wide range of techniques and problems: the Anderson impurity problem, Functional Renormalization Group, heavy-fermion systems, Fano resonance, transport, the Keldysh formalism, and unconventional superconductivity.

More importantly, Brazil taught me how to move from one problem to another, how to start learning something completely new when necessary, and how to continue when a seemingly promising path suddenly disappears.

Perhaps that is the real meaning of the second dream.

The first dream was fulfilled in a rather magical way - I found myself surrounded by some of the great minds of physics.

The second dream was repeatedly shattered.

Yet, strangely enough, it was the second one that perhaps helped shape me more deeply as a physicist.

Brazil may not have given me the publications I had hoped for. But it gave me something more difficult to measure: a much broader view of physics, the courage to start again, and, above all, a deeper love for the subject. Further, the wonderful people, magnificent nature and carefree atmosphere everywhere and joyful culture put no pressure onto me so that at the end of two years my mind and soul were greatly nourished for the next phase of life.

For that, I will always remember Brazil.

The Lonely Palm Tree

Prof. Saptarshi Mandal
Year of joining - 2015 ● Theoretical Condensed Matter Physics

The Sun leaving the sky to the Moon
the sheet of darkness descending soon.

Finally, the day-long trial getting over,
on the way to their sweet shelter,

they found you, the lonely Palm tree,
a gift from nature, rendered free.

Thy offerings, plenty, sweet and sour,
enough to add color in that hour.

Forgetting where they stood in age,
little children came out of the cage.

Awakening from the dream, the girl murmured,
"We were friends in another life, in a distant past."

"Yes, now picking up the plums from the dust,"
The boy replied.

Far away from that beautiful place,
free from the shackles of time and space,
I wonder - friends were they indeed?

For it was three:

that boy, that girl, and in Trieste,
that lonely Palm Tree.

The Accidental Light That Changed Science

Sayari Ghatak
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Every day, scientists from remarkably different fields walk into the same giant circular building, carrying very different questions. A neuroscientist hopes to understand why proteins in the human brain suddenly misfold, eventually leading to Alzheimer's and Parkinson's disease. An engineer wants to watch lithium ions move through a battery while it charges and ages, searching for longer-lasting and safer energy storage. An archaeologist arrives with a charred manuscript whose hidden words have remained unread for centuries, while a palaeontologist hopes to look inside a dinosaur fossil without removing a single grain of rock. Elsewhere in the same building, a physicist investigates quantum materials, searching for entirely new states of matter that may one day transform future technologies. Their questions couldn't be more different. Yet every one of them relies on the same beam of light.

That beam of light has a remarkable story of its own. Like many great discoveries, its story began with an accident. In the 1940s, physicists building powerful particle accelerators called synchrotrons to explore the fundamental building blocks of matter noticed that electrons lost energy as brilliant flashes of light whenever powerful magnets bent their paths. To the accelerator physicists, those brilliant flashes were nothing more than wasted energy, quietly stealing power from the very particles they were trying to accelerate. Yet what seemed like a problem soon became one of the most powerful scientific tools ever created.

Today, this light is known as synchrotron radiation.

But what makes a speeding electron produce light in the first place? The answer lies in one of nature's most elegant laws: whenever an electrically charged particle accelerates, it emits electromagnetic radiation. As billions of electrons race around a giant circular ring at almost the speed of light, powerful magnets continuously bend their paths, causing them to emit intense bursts of radiation.

If that sounds familiar, it's because synchrotrons and CERN's Large Hadron Collider are close cousins both giant rings where particles race at nearly the speed of light. But they were built for entirely different purposes. *The crucial difference lies in the choice of particle.* CERN accelerates protons because their enormous mass allows them to retain their energy until they collide, revealing new fundamental particles. Synchrotrons deliberately choose electrons for exactly the opposite reason. Nature gives lighter particles a strange advantage: when forced around a curve, they radiate dramatically more energy than heavier particles. In fact, the emitted power depends on the inverse fourth power of the particle's mass. Since an electron is nearly 2,000 times lighter than a proton, it emits more than ten trillion times as much radiation under the same conditions. What once frustrated accelerator physicists became the very reason synchrotrons were built.

The radiation emitted by the electrons spans almost the entire electromagnetic spectrum - from infrared and visible light to ultraviolet and X-rays. For many experiments, however, X- rays are the real treasure. Their wavelength is comparable to the spacing between neighboring atoms, allowing scientists to explore matter atom by atom. Unlike the X-rays produced in a conventional laboratory, synchrotron X-rays are exceptionally intense, highly focused and can be precisely tuned to different energies. Rather than simply taking an image, they allow scientists to determine atomic structures, probe the local chemical environment of specific elements, follow chemical reactions in real time, and detect signals far too weak for ordinary X-ray sources to reveal.

Producing these extraordinary X-rays, however, is only half the story. Scientists capture the beam and guide it through long experimental corridors called beamlines, each leading to a specialized experimental station designed to answer a different scientific question.

Today, from France and Japan to Brazil and India's own Indus-2, these giant rings of light quietly power discoveries every day. In early 2020, it was exactly this kind of light - at the Diamond Light Source in the UK - that revealed the atomic structure of the SARS-CoV-2 main protease, the enzyme the virus needs to replicate. Within weeks, that structure let researchers screen thousands of candidate molecules against it, kick-starting the search for COVID-19 antiviral drugs. The same beam that maps a virus's weak point also probes batteries, fossils, and ancient manuscripts down the hall. *The beam is the same; only the questions change.* And perhaps, somewhere at the end of one of those beamlines, lies the answer to a question we haven't even learned to ask yet.

Dark Matter detection using Quantum Sensors

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The Dark Matter Problem: The nature and origin of Dark Matter is one of the major open problems today in Cosmology and Particle Physics. The observed gravitational effects of Dark Matter can be explained by a non-baryonic component which dominates the universe, but its microscopic properties and production mechanism is still unknown.

Evidence for dark matter comes from observations at many different scales. Stars in galaxies rotate much faster than would be expected if they were composed solely of the visible matter we can see. The bending of light by galaxies and galaxy clusters (called gravitational lensing) reveals more mass than just stars and gas. On even larger scales, the formation and fragmentation of cosmic structures, as well as patterns in the cosmic microwave background, provide further evidence of a large, invisible part of the universe. These observations tell us something significant: There is more matter in the universe (called dark matter) than what we observe and we have considerable evidence of what dark matter does, but we still dont know what dark matter is.

For decades, a major possibility has been that dark matter consists of new, weakly interacting particles. This picture has motivated a great deal of experimental work, from underground detectors searching for rare interactions to particle colliders attempting to create new particles. However, dark matter is not necessarily made of extremely heavy particles, it may be composed of particles with very light mass.

Ultralight Dark Matter (ULDM):

ULDM is a class of DM whose masses range from 1 eV to 10^{-22} eV. Candidates in this class behaves like a wave rather than individual particles due to their extremely small masses; axions and axion-like particles (ALPs) are one of the examples of such ultralight dark matter. The QCD axion is particularly well motivated since it was originally introduced as a solution to the Strong CP problem and also arises naturally in several high-energy and string-theoretic frameworks.

With such a small mass, its de Broglie wavelength can be very large, larger than microscopic scales and, for very light particles, even larger than astronomical distances. This changes the most practical way to describe dark matter. Instead of thinking of the dark matter halo as a large collection of individual particles floating around in the galaxy, we can, with a very good approximation, describe it as a coherent field extending through space. In this picture, the field undergoes oscillations, which can be schematically represented as

$$\phi(t) \sim \phi_0 \cos(\omega t + \theta),$$

where ϕ_0 is the amplitude of the field, ω is its oscillation frequency, and θ represents its phase. The oscillation frequency is directly related to the mass of the field. In natural units, where $\hbar = c = 1$, one has approximately $\omega \approx m_\phi$.

Thus, the mass of an ultralight dark-matter particle determines not only how strongly its quantum nature itself, but also the characteristic frequency at which the associated field oscillates. This field picture also introduces the concept of coherence. Field oscillations are not completely random from point to point or from moment to moment in phase. Instead, they are correlated over characteristic coherence times and coherence lengths. As a result, an experiment on Earth could, theoretically, detect a nearly continuously oscillating background as the solar system moves through the galactic dark-matter halo.

However, it is important to clarify what is meant by saying that ultralight dark matter behaves like a "wave." This does not mean that dark matter is an electromagnetic wave like visible light or radio waves. Rather, the underlying quantum field may consist of a huge number of particles in a highly populated state. In this regime, the collective behavior of the field can be described very accurately by a classical, coherently oscillating wave.

Effects of ULDM on ordinary matter:

Different models of ULDM allow for different types of interactions although weakly, with the particles and fields of the Standard Model. In some cases, the oscillating field could cause small periodic variations in quantities that determine the properties of ordinary matter, such as the fine-structure constant α, the electron mass me, or the masses of quarks. Schematically, one can think of it like this:

$$\begin{aligned} \alpha &\to \alpha(t) \\ m_e &\to m_e(t) \\ m_q &\to m_q(t) \end{aligned}$$

where the time dependence is driven by oscillations in the dark-matter field. The size of these variations may be extremely small, but their periodic nature provides an important clue to detection. Change in these fundamental parameters matter a lot because the properties of atoms are determined by them. The energy levels of an atom depend on the masses of its constituent particles and on the strength of electromagnetic interactions. Consequently, even a tiny change in a fundamental constant can produce a tiny shift in the energy difference between two atomic states.

An atomic clock exploits this fact. At its core, an atomic clock uses a highly stable transition between two atomic states as a reference frequency. A laser or microwave signal is tuned to this transition, and the frequency of the signal can be measured with extreme accuracy. So, In a nutshell, an atomic clock is not just a device for keeping time, it is an extremely precise measure of the properties of atoms.

If we imagine an ultralight dark-matter field moving through the laboratory. If it slightly changes one of the fundamental parameters governing the atomic transition, the transition frequency itself will oscillate. The clock will then experience a small periodic shift in its measured frequency. The challenge is that the expected effect is incredibly small. Real laboratories are full of sources of noise: temperature fluctuations, magnetic fields, vibrations, electromagnetic interference, and imperfections in experimental equipment can all alter the measured frequency. Therefore, a potential dark-matter signal must be separated from these common environmental effects. However, the underlying idea is very simple. We do not necessarily need to observe the dark-matter field directly. Instead, we can look for the tiny changes it may leave on matter.

Using Quantum Technology for ULDM detection:

Atomic clocks are not the only system that can be used to discover subtle effects of ultralight dark matter. The same basic idea of using an extremely precise quantum system to observe a small, periodic perturbation could be implemented in many different ways.

One promising approach uses atomic interferometers. In an atomic interferometer, atoms are placed in a quantum Superposition of different paths and then recombined. The accumulated relative phase between these paths can be Measured with extreme precision. If an ULDM field interacts with atoms, it can produce a small change in their phase or motion. Instead of looking for changes in the frequency of the atomic clock, one can search for dark matter induced changes in atomic interference patterns.

Another possibility involves optical cavities. These devices confine light between highly reflective mirrors that are sensitive to extremely small changes in the properties of the light or the cavity itself. If an ULDM field causes a tiny variation in fundamental constants, it may slightly modify the optical properties of the system. By monitoring the cavity with sufficiently high precision, one can search for the characteristic oscillation expected from the dark matter field.

Perhaps an even more powerful idea is to use multiple quantum sensors in different locations to exploit an important

property of ULDM, which is Coherence. Common environmental disturbances like temperature fluctuations, vibrations, or electrical disturbances that affect one lab are usually local and will not necessarily have the same effect on another. However, a true dark matter field that extends throughout space and can remain coherent up to a certain distance. Therefore, if two distant sensors observe a matching oscillation at the same frequency and with the same phase relationship, it would be difficult to interpret that correlation as common lab noise. Therefore, a network of sensors can provide information that a single experiment cannot provide.

What Would a Dark-Matter Signal Look Like?

If we assume that an ultralight dark-matter field is oscillating through the laboratory. The simplest expectation is a tiny periodic variation in the quantity being measured. Schematically, such a signal could take the form

$$\delta X(t) = A\cos(\omega_{\rm DM}t + \theta),$$

where A is the amplitude of the variation, ω_{DM} is the characteristic angular frequency associated with the the mass of the dark-matter field, $\omega_{\mathrm{DM}} \approx m_\phi$ in natural units, and θ is its phase.

The amplitude A could be very small, making the signal virtually indistinguishable from experimental noise. However, the signal would have several properties that make it interesting. First, it would be at a specific frequency determined by the dark-matter mass. Second, it would persist over many oscillation cycles, rather than appearing as a random fluctuation. Third, because the dark-matter field is coherent over a limited region of space and time, measurements made with different sensors could show correlations. These properties provide an effective way of distinguishing a potential dark-matter signal from ordinary noise.

There is another unique possibility. Because the Earth passes through a galactic dark-matter halo, the signal does not need to be completely stable in its spatial or temporal properties. The motion of the solar system through the dark-matter distribution can leave faint traces in the observed signal. Therefore, a sufficiently sensitive network of detectors can detect not only oscillations but also specific spatial and temporal structures associated with the fields passing through the galaxy. In this sense, the experiment will not only tell us that "something is oscillating." It can tell us that an invisible field with a specific mass, interaction, and coherence structure is passing through our laboratory.

However, detecting oscillations does not, in itself, constitute the discovery of dark matter. Experiments are surrounded by many sources of unwanted signals. Temperature changes can alter atomic frequencies, magnetic fields can distort energy levels, vibrations can affect optical systems, and fluctuations in lasers and electronics can produce distinctly periodic signals. The environment outside the lab can also have subtle effects. Therefore, a definitive finding will require more than simply observing periodic changes. So, Instead of relying on a single experiment, one can compare atomic clocks, optical systems, atom interferometers, and other precision instruments. If signals with the same intrinsic frequency and relative responses predicted by the same dark-matter model are observed in different experiments, the case for a new physical field becomes very strong.

Conclusion:

Our understanding of dark matter has reached a point where we have strong evidence for its existence, and we can accurately describe its gravitational effects on the universe. Yet, even after decades of searching, its microscopic identity remains unknown. Ultralight dark matter offers a fascinating possibility. If dark matter is represented by a light, uniformly oscillating field, its presence could be detected not by big collisions, but by extremely small changes in the physical systems around us. Atomic clocks, atom interferometers, optical cavities, and other quantum sensors offer a completely different way to search for such signals.

Traditionally, the search for new particles has often meant building more powerful accelerators or detectors. The search for ultralight dark matter suggests a complementary strategy of measuring very precise and observing the tiny effects of particles that may already be passing us by. Therefore, the dark matter around us may not show its presence with a flash of light or a powerful collision. Instead, it may reveal itself through a subtle rhythm hidden in the ticking of a clock, the phases of atoms, or the resonances of quantum systems. New physics may be hidden in a tiny frequency shift, a tiny phase difference, or a faint oscillation buried beneath the noise of our environment. Perhaps the next breakthrough in particle physics will come not from creating something new, but from learning to listen more carefully to what is already around us.

From Brilliant Scientists to Transformative Leaders: Rethinking Science Leadership in India

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The next frontier of Indian science may not be a new laboratory, a new instrument, or even a new breakthrough. The country has a large and increasingly ambitious scientific community, a rapidly expanding higher-education ecosystem, a young population of researchers, growing investment in research and innovation, and an increasingly confident aspiration to contribute to global science and technology. Yet, as India's scientific ambitions grow, an important question deserves greater attention: Do we have enough scientists who are prepared not only to do excellent science, but also to lead people, institutions, collaborations and most importantly bring change?

A brilliant researcher may discover a new material, develop a new process, build an impressive laboratory, publish high-citation papers or create a successful technology. But scientific progress at scale requires something more. It requires people who can bring together diverse expertise, mentor young researchers, communicate across disciplines, navigate institutions, build partnerships, manage failure, make ethical decisions and translate scientific knowledge into societal value. This is perhaps one of the most important transitions facing Indian science today.

From the individual scientist to the scientific ecosystem: For much of the twentieth century, the image of a successful scientist was centerd on individual achievement: the important discovery, the influential paper, the prestigious award, the laboratory and, increasingly, the research grant. These remain important. But contemporary science is becoming progressively less individualistic. For example, climate change cannot be addressed by a single discipline. Artificial intelligence is transforming virtually every field of science and engineering. Semiconductor technologies require materials scientists, physicists, chemists, engineers and computational experts to work together. Precision medicine brings together biology, medicine, data science and engineering. Sustainable agriculture requires scientists to collaborate with farmers, economists, policymakers and industry. The most important scientific questions of our time increasingly sit between disciplines rather than within them. This changes the meaning of scientific leadership. The scientist of the future must be able to ask not only, "What can I discover?" but also: "Whom should I work with?"; "How can this knowledge move beyond my laboratory?"; "How do I create an environment where younger scientists can do better than I did?"; "How do I build a team that remains strong even when I am no longer leading it?"

New leadership expectations: Leadership is no longer being viewed simply as something that happens after one becomes a departmental head, Dean, Director or Vice-Chancellor. It is increasingly seen as a capacity that should be cultivated throughout an academic career. There is a significant shift in thinking. The National Education Policy (NEP) 2020 explicitly calls for multidisciplinary higher education, greater faculty and institutional autonomy, stronger research ecosystems, institutional leadership, and a National Research Foundation to catalyse research in universities and colleges. Importantly, the policy recognizes that institutional transformation depends on effective academic leadership and calls for identifying talented faculty early and developing them through a ladder of leadership positions. The establishment of the Anusandhan National Research Foundation (ANRF) is another important development. Created through the ANRF Act, 2023, the foundation is intended to provide strategic direction to research, innovation and entrepreneurship across a broad range of disciplines and to strengthen connections among academia, industry and government. Such an ecosystem creates opportunities, however, opportunities alone do not create impact. They require scientists/faculties who can recognise opportunities, formulate meaningful questions, build collaborations, write competitive proposals, manage teams, communicate with stakeholders and take responsibility for outcomes. We must understand that the grant is not the destination. For an early-career scientist, obtaining a research grant can feel like the ultimate validation. It is a significant achievement. But receiving the grant is only the beginning. A successful research project requires much more than scientific knowledge. There are students to mentor, experiments to plan, timelines to manage, collaborators to coordinate, instruments to access, data to interpret, papers to write, reports to submit and unexpected failures to handle. And then comes the more difficult question: What happens after the project ends? Does the research lead to another question? Does it create a technology? Does it inform policy? Does it generate a startup? Does it benefit a community? Does it train a generation of researchers? Does it build an enduring research group? A research leader therefore has to think beyond the immediate deliverable. The best scientific leaders build ecosystems around ideas.

The laboratory, the first leadership school: Perhaps the most important place in which a scientist learns leadership is their own laboratory. A Principal Investigator may be formally in charge, but leadership cannot be sustained through hierarchy alone. A doctoral scholar who is afraid to question an assumption may produce technically correct but intellectually limited research. A student who receives criticism without mentoring may lose confidence. A postdoctoral researcher whose contribution is not acknowledged may disengage. A team where information and credit are concentrated at the top may eventually lose trust. Conversely, a research group where people can question, collaborate, disagree respectfully, learn from failure and receive credit fairly can become extraordinarily productive. This is why research leadership is fundamentally human leadership. Scientific competence may get a person to the laboratory. But empathy, communication, fairness, mentoring and the ability to build trust determine what happens inside it. The leader's most important output may therefore not be a paper. It may be the people who leave the laboratory better equipped to lead their own scientific journeys.

Collaboration is no longer optional: One of the most powerful shifts in scientific leadership is moving from individual ownership to collective purpose. This does not mean that individual excellence becomes irrelevant. Rather, it means placing individual excellence within a larger mission. Indian science has a remarkable tradition of institutions and centers of excellence. But the complexity of contemporary scientific problems demands stronger connections between them. The question is no longer simply whether individual institution can become excellent independently. The more important question is: Can excellence connect? This requires distributed leadership. No single scientist can possess all the expertise required to solve a complex problem. Effective leaders therefore learn to create teams in which expertise is distributed rather than concentrated. The leader becomes less of a person who has all the answers and more of a person who knows how to bring together the people who can find the answers. The emerging scientific leader is increasingly a boundary-spanning professional. This is especially important in India, where scientific institutions often have different mandates, cultures and administrative systems. A young scientist who can build bridges across these boundaries has a disproportionately large potential for impact. This is why skills such as negotiation, communication, project management, stakeholder engagement and conflict resolution should no longer be treated as peripheral to scientific training.

Leadership must begin early: Traditionally, academic leadership was often treated as a senior-career activity. A scientist first became a researcher, then a Professor, then perhaps a Head of Department, Dean, Director or Vice-Chancellor. The problem with this model is simple: leadership cannot be learnt overnight after receiving an administrative appointment. There should be a smooth transition in the science of saying we. Scientific careers can be highly individualistic. We count papers. We count citations. We count grants. We count patents. We count awards. Of course, these metrics have their place. But leadership introduces another vocabulary: we built; we mentored; we collaborated; we enabled; we translated; we served. The transition from "I" to "we" is not a loss of individual identity. It is an expansion of impact. A scientist who publishes ten excellent papers creates knowledge. A scientist who builds a team that produces hundreds of excellent researchers over several decades creates a scientific institution. The second form of contribution may be less visible initially, but its influence can be much larger.

The uncomfortable question of recognition: Scientific leadership also requires us to rethink how we recognise achievement. If we reward only individual publication counts, grants, awards, researchers may focus disproportionately on individual recognition. But if institutions also value mentoring, team building, interdisciplinary collaboration, societal engagement, technology translation, teaching innovation and institutional service, they send a different message about what academic excellence means. This broader definition of excellence is essential for developing healthy academic cultures. The scientist who quietly mentors a generation of students may not appear in a citation database for that contribution. The faculty member who brings together researchers from five departments may not have a single metric capturing the collaboration. The person who creates an inclusive research environment may never receive a conventional scientific award for doing so. Yet these are forms of leadership that determine whether scientific institutions thrive.

What should Indian scientific leadership look like? We must realize that there cannot be one single model. India is too diverse for a single template. A successful research-intensive institute may require one form of leadership. A state university may require another. A national laboratory may have different priorities from an agricultural research institute. A young university may need entrepreneurial leadership, while an established institution may need cultural transformation. Yet certain principles are universal: Lead with purpose; Build people, not just projects; Collaborate generously; Communicate clearly; Make ethics non-negotiable; Share leadership; Prepare successors. The ultimate test of a leader is what happens after they leave.

The Classroom I Remember, The India I Imagine

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I still hear that morning bell. Not the harsh mechanical ring of today, but the deep clanging music of a bronze bell that hung in the courtyard of my primary school. It called us from our homes, from our dreams, from our half eaten breakfasts, and gathered us together under the open sky. We stood in crooked lines, singing prayers we barely understood, watching the flag climb its pole like a slow orange sun. Then we marched into our classrooms, rows of wooden benches, a dusty blackboard, and the faint smell of chalk and old books. That was the classroom I remember. For years, I thought that was all education was supposed to be. Lessons, homework, examinations, the thrill of holidays, the sting of low marks, and the relief when the final bell rang. But somewhere between childhood and now, I began to wonder.

What if that tiny classroom, so small on the map of India, was actually one of the most powerful places in the country? Not because of what children memorise there, but because of what they become there. Think about it. A child sits in that room for five or six years. In those years, she learns not just maths and science, but something far more important. She learns how to see the world. What if, instead of only reading about diseases in a textbook, she walked into her neighborhood and taught her grandmother why stagnant water is dangerous? What if, instead of just drawing a tree, she planted one and watched it grow alongside her, year after year? What if, instead of only learning about rivers in geography, she learned why her own village pond was drying up and what she could do about it? That is not just education. That is life itself.

I remember one afternoon in school, not from a textbook, but from life itself. Our teacher asked us to make something with our hands. Anything. We made little clay pots, paper flowers, painted stones, and set up small stalls in the schoolyard. We sold them to each other, not for real money, but for paper tokens. That day, I discovered something. I discovered that I could create something that others wanted. I discovered that I could speak to people, convince them, laugh with them, and learn from them. I discovered that an idea, no matter how small, could become something real. That one afternoon taught me more about confidence, communication, and courage than any examination ever did. And I thought, what if every child had more days like that?

Some lessons are not written on the blackboard. They are written in the silences, in the tears a child hides, in the laughter that erupts unexpectedly, in the quiet friendship between two children from different homes, different languages, different gods. Our country is a garden of a thousand flowers, but we are not always taught to admire the beauty of our differences. We are sometimes taught to fear them. What if the classroom became the place where children celebrated every festival together, Diwali, Eid, Christmas, Pongal, Bihu, not as separate holidays, but as shared joys? What if children learned, not through lectures, but through stories, songs, and food, that India's strength is not in its sameness, but in its vast, beautiful, bewildering diversity? What if they learned that being different was not a threat, but a gift?

There is a quiet revolution happening in India today, but it is not on the news and it is not in the streets. It is in the hearts of children who are learning that their feelings matter. We never spoke about emotions in my classroom. We were told to be strong, to not cry, to not complain. But now I think, what if we had learned that fear and sadness are not weaknesses? What if asking for help is not shameful? What if listening to a friend in pain is one of the bravest things a person can do? A generation that learns to care for its own heart and the hearts of others will not grow up to be a nation of strangers. It will grow up to be a nation of healers.

I have come to believe that education is not a ladder. It is a circle. A child learns something in a small village classroom. She takes it home and teaches her mother about clean water. Her mother tells her neighbor. The neighbor tells her family. The family influences the community. And the community, slowly, quietly, invisibly, begins to change. That child grows up. Maybe she becomes a doctor, maybe a teacher, maybe an environmental scientist, maybe a mother. But whatever she becomes, she carries that seed with her and plants it again somewhere new. That is how nations are built. Not by grand speeches or towering buildings, but by millions of small acts of learning, sharing, and caring.

I imagine an India where every classroom is a window, not a wall. Where children learn not to fear examinations, but to love questions. Where a child from a small village dreams of becoming a scientist, not because she read about one, but because she experimented with her own hands and discovered the joy of why. Where a boy from a crowded city learns to plant a tree and grows up to protect a forest. Where every child knows that her feelings are valid, her voice matters, and her future is not limited to a few narrow paths. That is the India I imagine. Not perfect, not finished, but possible.

Today, when I close my eyes, I still hear that morning bell. But it no longer calls me to a classroom of wooden benches and chalk dust. It calls me to a vision, a vision of millions of children, sitting in millions of classrooms across this vast country, discovering not just subjects, but themselves. And I smile, because I know that those children will grow up to be the architects of a new India, an India that is healthier, wiser, kinder, and more united. And one day, when they look back at their school days, they will remember not just what they were taught, but who they became. The classroom I remember is small. The India I imagine is boundless.

Why Is Walking Easier Than Pointing?

Based on John Toner's Les Houches Lectures
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Imagine a million people standing in a huge open field covered by thick fog. Imagine a million people standing in a huge open field covered by thick fog. Now give everyone a simple instruction:

> *"Point in the same direction."*

It sounds easy. Each person can look at their neighbors, see where they are pointing, and adjust their own direction accordingly. The actual direction does not matter, what matters is that everyone agrees on the same direction at a given time. Can everyone point in the same direction ?

There is a problem.

Suppose the first person points in a particular direction. Their neighbor copies this direction, but suppose, makes a tiny error. The next person copies that direction and makes another small error. Then the next one does the same.

No individual has made a serious error. Everyone is doing their best to follow the people around them.

And yet, after going far enough across the field, these tiny errors accumulate.

People at one end of the field may be pointing north-east, while people thousands of metres away may be pointing south-west.

In other words,

> *Local agreement does not necessarily produce global agreement.*

Now change just one word in the instruction. Instead of

> *"Point in the same direction,"*

say

> *"Walk in the same direction."*

Something remarkable can happen. The people can now form a coherent moving crowd: despite the inevitable small errors and fluctuations, the group can move collectively in one direction. This is the surprising phenomenon behind John Toner's famous question:

> *Why is walking easier than pointing?* [1]

What Happened? Pointing Seems Almost The Same As Walking!

At first, this may sound like a trick. After all, if everyone is walking north, aren't they simply pointing north while moving? The crucial difference is that, when people walk, their position changes.

Suppose everyone is initially walking in the same direction, and one person makes a small directional error. This person does not remain surrounded by the same neighbors. As the crowd moves, they encounter new neighbors, and because each person tends to align their motion with their local neighborhood, these local alignment interactions continually redistribute and smooth out directional fluctuations. The disturbance is carried along by the motion instead of simply accumulating in one place.

Motion continually mixes the system. Pointing does not.

If everyone simply stands still, a small difference in orientation has no mechanism for being swept away by the motion of the group. Local errors can accumulate over large distances.

This distinction - *static alignment versus moving alignment* - is at the heart of a major result in the physics of collective behavior.

The Role of Dimensions:

The question that we ask,

> *What happens if everyone simply stands still and tries to point in the same direction?*

is actually an incomplete one. Because the answer depends strongly on the number of spatial dimensions. The reason is that random fluctuations in people's directions become more or less important depending on the dimensionality of the space. To see this, let us consider one, two, and three dimensions separately.

One dimension - fluctuations have nowhere to go:

Imagine a long line of people, with each person trying to point (not walk) in the same direction as their neighbors:

→ → → → → →

Now suppose one person makes a small error and turns slightly:

→ → ↗ → → →

That small disturbance can influence the people next to them, which in turn influence the next people, and so on.

The important point is that the system has only one spatial direction in which these disturbances can spread. There is no surrounding region that can provide an independent source of alignment.

As we look farther and farther along the line, small fluctuations accumulate. Even though each individual makes only a tiny error, the collective effect becomes increasingly important.

Thus, in one dimension, maintaining a common direction is particularly difficult.

Two dimensions - more neighbors, but still not enough:

Now place the people on a flat surface:

→ → → → →
→ → → → →
→ → → → →
→ → → → →

Now each person has neighbors not only to the left and right, but also in other directions. One might therefore expect the additional neighbors to make global alignment easy.

They certainly help, but something remarkable still happens.

The fluctuations can occur over increasingly large length scales. Instead of the direction changing abruptly from one person to the next, imagine that it slowly bends across the system:

→ → ↗ ↗ ↑

Locally, the people are still pointing almost in the same direction as their neighbors. If we look at a small region, the system may appear highly ordered.

But if we keep zooming out, these small deviations can accumulate into a large change in direction.

There can be fluctuations on every scale: small fluctuations involving a few people, larger fluctuations involving hundreds of people, and still larger fluctuations involving enormous regions of the system.

In two dimensions, the combined effect of these long-wavelength fluctuations is strong enough to destroy conventional long-range orientational order in an equilibrium system at finite temperature.

This is one of the central results captured by the Mermin - Wagner - Hohenberg theorem.

Three dimensions - fluctuations become less dangerous:

Now imagine that the people fill a three-dimensional volume. A person is no longer surrounded merely by neighbors on a surface. There are neighbors in every direction around them. More importantly, the effect of long-wavelength fluctuations becomes weaker as the dimensionality increases.

Fluctuations are still present. People can still point slightly differently from one another, and the direction can still vary from place to place.

But in three dimensions, these fluctuations do not accumulate strongly enough at large distances to destroy the overall order.

A three-dimensional equilibrium system with a continuous symmetry can therefore develop a common macroscopic direction:

⇶ ⇶ ⇶ ⇶ ⇶

The important lesson is therefore not simply that three dimensions have "more neighbors."

The deeper point is that the importance of long-wavelength fluctuations depends on dimensionality. In one and two dimensions, these fluctuations are sufficiently strong to destroy conventional long-range orientational order in equilibrium systems with short-range interactions. In three dimensions, their effect remains finite, allowing long-range order to survive.

This gives us the basic picture:

> *In one and two dimensions, fluctuations are strong enough to destroy conventional long-range alignment in equilibrium systems; in three dimensions, they are not.*

And this is precisely what makes the walking problem so interesting.

If stationary people cannot maintain long-range alignment in two dimensions, how can a flock of birds, a school of fish, or a collection of self-propelled particles move coherently across a two-dimensional world?

The answer is that walking introduces something pointing does not have:

> *motion itself.*

The particles are no longer merely carrying an orientation. They are moving through space, carrying their collective motion with them. To understand this more clearly let us look at the theorem behind this.

The Theorem Behind The Story:

We can now state the result that lies at the heart of the pointing problem. The Mermin - Wagner - Hohenberg theorem [2] states that :

> *A system in thermal equilibrium at finite temperature, with sufficiently short-ranged interactions, cannot spontaneously break a continuous symmetry in one or two spatial dimensions.*

In simpler language, consider a two-dimensional system whose rules do not prefer any particular direction. For example, imagine a collection of tiny arrows that interact only with nearby arrows and tend to align with them. If the system is in thermal equilibrium, random fluctuations become increasingly important on larger and larger length scales. As a result, the system cannot maintain a single common direction throughout an arbitrarily large region.

This is why our imaginary crowd of people who are merely **pointing** cannot maintain perfect long-range alignment in two dimensions, provided the situation satisfies the assumptions of the theorem.

At this point, however, a natural question arises.

> *Birds can fly collectively in one direction which also means they are pointing in one direction, but that happens maybe because they are in three dimensions or is there something else? But then again, what about, bacteria, or artificial particles moving on a two-dimensional surface? How can they collectively move in one direction (and hence point in one direction). And what about a crowd of people walking on a flat ground? Why don't they contradict the theorem?*

The answer is that the theorem applies to systems in **thermal equilibrium**.

A flock of birds, a school of fish, a group of bacteria, or a collection of self-propelled particles is not an equilibrium system.

Equilibrium versus non-equilibrium:

To understand the difference, imagine a box containing ordinary particles. At equilibrium, the particles are constantly moving because of thermal motion, but there is no continuous supply of energy driving the system in a particular way. Energy is exchanged between the particles and their surroundings, and after sufficient time the system settles into a statistical state described by equilibrium thermodynamics.

Now consider a bacterium. It continuously consumes chemical energy and converts that energy into motion. A bird uses energy from its metabolism to flap its wings. A person uses chemical energy stored in their body to walk. A self-propelled particle may use an internal or external energy source to move through its environment.

These systems therefore require a continual input of energy to maintain their motion. They are **non-equilibrium systems**. This distinction is crucial because the Mermin - Wagner - Hohenberg theorem does not forbid long-range order in an arbitrary system. It makes a statement about a particular class of systems: equilibrium systems with continuous symmetry and sufficiently short-ranged interactions. A moving flock falls outside this class.

Why walking escapes the theorem:

Return once more to our two-dimensional crowd. When everyone is simply pointing, their positions do not systematically change because of their orientation. A fluctuation in direction can therefore spread through the stationary system, and the long-wavelength fluctuations discussed earlier eventually destroy conventional long-range order.

When everyone is walking, however, the situation is fundamentally different. The particles are continuously moving through space. Their velocity is therefore not merely an orientation; it also determines how they move from one region to another.

Suppose a small group develops a slightly different direction of motion. As the particles move, they encounter new neighbors. The local alignment interactions act on these new neighbors, while the motion simultaneously transports the disturbance through the system.

In other words, the system has acquired a new mechanism that does not exist for stationary pointers:

> *the order itself is being transported by the motion.*

This transport, or **advection**, changes the way fluctuations behave on large scales.

Thus, the collective motion of a flock is not obtained simply by taking an equilibrium system of arrows and making the arrows move. The motion fundamentally changes the dynamics of the system.

This is why a two-dimensional collection of self-propelled particles can develop collective motion without contradicting the Mermin - Wagner - Hohenberg theorem.

The same basic idea applies to flocks of birds, schools of fish, bacterial colonies, and many artificial active-particle systems.

They are not equilibrium systems that have somehow found a loophole in the theorem. Rather, they belong to a completely different class of physical systems. And this is the central reason why the apparently simple question

> *"Why is walking easier than pointing?"*

has such a deep answer.

> Pointing is an equilibrium-like alignment problem in which fluctuations can destroy long-range order. Walking is an active, non-equilibrium process in which motion itself transports the order and changes the way fluctuations accumulate.

The birds are therefore not violating the theorem. They have simply stepped outside the conditions under which the theorem applies.

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[2] N. D. Mermin and H. Wagner, “Absence of Ferromagnetism or Antiferromagnetism in One- or Two-Dimensional Isotropic Heisenberg Models,” *Physical Review Letters* **17**, 1133–1136 (1966). doi:10.1103/PhysRevLett.17.1133.

Through the Corridors of Time: Messages from IOP members

There is something strange about watching alumni walk back through these gates. They pause at the main gate a little longer than we do, glance at emails like they are expecting familiar names and/or messages, and smile at things we have stopped beholding before: the broken and alive spaces near the library, fields, hostels, laboratories, the sitting places in offices, and the voices tunneled through the corridors. For us, this campus bears the everyday activities, i.e., the deadlines, lab sessions, half-finished assignments, the version of life we are too close to see clearly yet. For them, it is a memory they have toted with them, one that apparently grows fonder with distance. What Alumni Day subtly teaches us is that the ordinary, exhausting, in-progress life we are living right now is someone else's nostalgia in the making. It is the proof that this phase, whatever frame it is currently in, eventually settles into something worth returning to. Perhaps that is the real lesson to cherish these days now, instead of solely appreciating them in hindsight. Every institution dreams of this moment, when the students it once clasped close return, in the end, as the individuals it lent a hand in becoming.

Digbijaya Palai
Predoc-2019 batch • Experimental Condensed Matter Physics
PhD Student,
Institute of Physics.

It is a great pleasure and privilege to be part of the Alumni Day celebrations of the Institute of Physics, Bhubaneswar, an institution that has been an integral part of my journey as a researcher in nuclear astrophysics.

My association with IOP began as a young researcher, where the stimulating academic environment, inspiring mentors, and vibrant scientific interactions helped shape my interests in nuclear physics and nuclear astrophysics. The Institute gave me the freedom to explore challenging scientific questions and provided a strong foundation for my research career. Today, being associated with the same Institute as a faculty member is both an honor and a deeply fulfilling experience. The journey from an alumnus to a faculty member has given me the unique opportunity to contribute to the same scientific environment that once nurtured me.

For me, IOP is more than an institution, it is a place of learning, discovery, memories, and lasting scientific relationships. I am grateful to all my teachers, mentors, colleagues, and friends who have been part of this journey. On this special occasion, I extend my warm wishes to all IOP alumni. May our continued association strengthen the IOP family, foster new collaborations, and inspire future generations of scientists.

Once an IOPian, always an IOPian!

Dr. Mrutunjaya Bhuyan
Year of joining - 2025 • Theoretical Nuclear Physics
Assistant Professor (E),
Institute of Physics.

My association with the Institute of Physics (IOP), Bhubaneswar, has played an important role in shaping the way I look at science. IOP taught me that good research is not only about obtaining a result; it is about asking the right question, understanding the physics behind an observation, and communicating it clearly. After my doctoral training at IOP, my research journey took me through laboratories in South Korea, the United States, and now back to India. During this journey, I have continued working on perovskite materials and solar cells, an area that has changed extraordinarily fast. What began as an emerging photovoltaic concept has developed into high-efficiency tandem devices, large-area modules, and early commercial deployment. It is exciting to see fundamental materials physics gradually moving toward technologies that may contribute to clean energy, sustainable buildings, agriculture, and even space power.As an alumnus, I remain grateful for the scientific foundation, discipline, and curiosity that I developed at IOP. I hope young researchers will remain open to interdisciplinary problems and will not be afraid to move between fundamental science and real-world applications. India needs both: deep scientific understanding and the confidence to translate that understanding into useful technology.

Dr. Pronoy nandi,
Predoc-2013 batch • Experimental Condensed Matter Physics
Ramanujan Faculty,
Dept of Physics, IIT Roorkee.

Life at the Institute of Physics, Bhubaneswar, has been a wonderful blend of research, learning, fun, and countless memorable moments. The institute has provided me with a great environment to learn and interact with people from diverse backgrounds. The discussions, seminars, and everyday interactions with fellow researchers have enriched my research journey and helped me grow along the way. Beyond academics, the institute community has fostered meaningful friendships and created many memorable experiences. Overall, my time at the Institute of Physics has been a truly enjoyable and memorable part of my journey.

Pujalin Biswal,
Predoc-2022 batch • Experimental Condensed Matter Physics
PhD Student,
Institute of Physics.

The days I spent at IOP were among the most beautiful days of my life, and I always feel nostalgic whenever I think about them. My learning curve changed tremendously during that period through my interactions with so many great scientists. Each individual is unique in their own way, but what I found most common among all of them was their immense enthusiasm and passion for science. I will always remain indebted to my supervisor, from whom I learned not only physics but also the values of life, socialism, and the importance of being a good human being. I am also fortunate to have met my sweetheart at this institution, who has always stood by me through both happiness and sadness. I deeply miss the long-night conversations with my friends and the endless discussions on physics with my research group over cups of tea. These memories will always remain close to my heart and will continue to be a cherished part of my life.

Dr. Ranjita K Mohapatra,
Predoc-2005 batch • Theoretical High Energy Physics
Asst. Professor, Dept. of Physics,
Rajdhani College, Bhubaneswar.

Looking back, my journey at the IOPB feels like much more than the years I spent studying physics. It was a period of growing up, learning to deal with uncertainty, finding confidence in myself, and slowly understanding what I wanted from life. I remember the long discussions with friends, quiet moments around the campus, shared worries before deadlines, small celebrations, and the simple routines that once seemed ordinary but now feel deeply precious. The Institute gave me more than academic training. It gave me friendships, memories, resilience, and a sense of belonging that I still carry with me. Since leaving, my journey has taken me to new places and experiences, but whenever I think of those years, I feel a special warmth. Some places become part of who we are, and for me, the IOPB will always be one of those places.

Dr. Rojalin Padhan,
Predoc-2017 batch • Theoretical High Energy Physics
Postdoc,
Dept. of Physics, Chung-Ang University, Seoul, South Korea.

My journey at IOP has been much more than a PhD in theoretical condensed matter physics. Over the years, this place has become a part of my life - a place where I have grown as a researcher and, more importantly, as a person. Life at IOP has brought its share of struggles, frustrations, long calculations and unanswered questions, but it has also given me some of my most memorable experiences. Conversations with seniors, juniors and friends have ranged from serious scientific discussions to completely informal conversations about life, plans, failures, dreams and everything in between. These interactions have made the journey richer in ways that go beyond research.

After office hours, when almost everyone has left, IOP takes on a different character. Sitting alone in my office, with the institute quiet around me, brings a sense of peace that is truly its own. At that hour, it feels like my little kingdom - just me, my work, my thoughts and a wonderful sense of freedom. The memories are not limited to physics. Those one or two hours spent playing badminton or volleyball, despite the not-so-perfect courts, somehow make the institute come alive in a completely different way. The games, laughter, arguments, and conversations that follow are moments I know I will deeply miss. As I approach the end of my PhD, I realize that I will miss much more than the research. I will miss the people, the conversations, the late nights, the games, the silence and even the everyday chaos. *Among all the fluctuations and uncertainties at IOP, I somehow found my collapsed ground state: sitting peacefully in my office chair at night.*

Sayak Bhowmik,
Predoc-2022 batch • Theoretical Condensed Matter Physics
PhD Student,
Institute of Physics.

My 25 years at IoP - A journey full with privilege: I joined the Institute on 22/08/2001 as a Faculty member. Since then I have had the privilege and honour to serve this great Institute of international per excellence. This was strongly footed on the research carried out by our champion scholars and postdoctoral fellows. Our Institute has always been running with a critical faculty strength and thus, our success story has been scripted mostly by our young researchers and faculty members with the help of a large number of frontline research facilities, national and international collaborations, the academic liberty, and our strong interpersonal relationship. It gives me an immense pleasure to celebrate the Alumni Day on 3rd September, 2026. I look forward to a great success of the Alumni Day programme planned by our scholars, postdocs, and the Director.

Prof. Tapobrata Som,
Year of joining - 2001 ● Experimental Condensed Matter Physics
Institute of Physics.

Here's to the ones that we got

Cheers to the "wish you were here, but you're not"

'Cause the drinks bring back all the memories

Of everything we've been through

Toast to the ones here today

Toast to the ones that we lost on the way

'Cause the drinks bring back all the memories

And the memories bring back, memories bring back you

- Maroon 5

Memory Lane




Dr. Abhishek Roy,
Postdoc, Soganag University & CQUeST, Seoul, South Korea.

Memory Lane

Dr. Arnob Kumar Ghosh,
Postdoc, Uppsala University, Sweden.

Memory Lane








Ohidul Alam,
PhD student, Institute of Physics.

Memory Lane






Dr. Paramita Maiti,
Senior Technical Superintendent, Indian Institute of Technology Hyderabad.

Memory Lane

Dr. Rojalin Padhan,
Postdoc,
Dept. of Physics, Chung-Ang University, Seoul, South Korea.

Memory Lane








Sheikh Moonsun Pervez,
PhD Student, Institute of Physics.