KARNATAKA PHYSICS ASSOCIATION (R.)

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KPA NEWSLETTER – 12 AUGUST 2026

Contents

Attention Please

KPA members and other contributors are requested to submit their write-ups (in English or Kannada) for the next issue of the Newsletter, scheduled to be published in **Nov 2026**.

FROM THE EDITORS

As usual, this issue of the newsletter contains a wide variety of articles that should be of interest to both physics' students and teachers alike.

The first article lists three 'filters' suggested by Sundar Pichai, CEO of Google, for students. Recently, a privately funded research institute named Lodha Institute for Theoretical Physics has been set up in Mumbai. The second article gives us some details about it.

The amazing story of Swami Jnanananda, who became a nuclear scientist from being a Himalayan monk, is described in the next article.

The importance of skill labs in schools is discussed in the next article. A brief account of the Belgian physicist Englert, who was one of the pioneers in advocating Higgs particles as well as the founder of the 'Standard Model of Particle Physics' and who passed away recently, can be found next.

The crisis resulting from the NEET examination is described in the next article.

What can be and what should be the role of AI in physics education is discussed in the next article.

A startling discovery that the axis of the Earth has been tilted due to excessive pumping out of groundwater is described in the next article.

There were all kinds of reactions to the famous EPR paper of 1935. The next article gives a brief account of the same.

Processing information faster with light signals instead of electrons is a modern discovery that is described in the next article.

The next article describes the structure, properties and applications of the earliest 'quantum stars', namely, the White dwarfs.

Some interesting facts about real and manufactured diamonds can be found in the next article.

The next article dwells on the important unsolved problem of quantum gravity and how time itself has to be understood differently.

The next article in Kannada gives a detailed account of the carbon cycle and the oceans – how it is changing now.

The next article summarises the common properties of nuclei.

A very recent achievement has been a technique that slows down light like matter. The next article gives an account of this incredible result.

Some interesting facts about nanomaterials can be found in the next write-up.

A summary of the strange properties of black holes – compiled by an enthusiastic high school student – can be found next.

The next article gives a historical account of the contributions of Kerala mathematicians in explaining several aspects of astronomy – something that is not available in our textbooks and not known to most people can be found in the next article.

A summary of the common properties of nuclei can be found in the next article.

A fascinating and incredible feat that has been achieved is slowing and stopping light in BEC. The next article describes how that has been done.

The editors are thankful to the authors for their contributions. Sincere gratitude is also expressed to the authors and publishers' whore open-source articles are selected here for publication for the benefit of students and teachers.

A summary of activities of KPA members and the webinars held during the past three months are documented here as usual.

KPA thanks Dr Muktha B. Kagali for designing and editing this newsletter at short notice, without any charge.

The editors welcome the reactions of the readers to the various articles and once again appeal to KPA members and others to contribute their articles for the next issue of the newsletter.

The Chief Editor

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A Century of Quantum Mechanics (1925–2025): The Revolution That Changed the World

A Century of Quantum Mechanics (1925–2025)

"One hundred years ago, a bold scientific revolution began—not with rockets or giant laboratories, but with ideas that challenged our understanding of reality."

In 1925, Werner Heisenberg introduced matrix mechanics, marking the birth of modern quantum mechanics. Within a year, Erwin Schrödinger formulated wave mechanics, while Paul Dirac unified these revolutionary ideas into a powerful mathematical framework. Together, their work transformed our understanding of atoms, light, and matter.

Today, quantum mechanics is no longer confined to research laboratories. It powers semiconductors, lasers, magnetic resonance imaging (MRI), GPS technology, fibre-optic communication, solar cells, and the emerging fields of quantum computing and quantum communication.

As we celebrate the centenary of quantum mechanics, we honour not only the pioneers who reshaped science but also the generations of physicists, teachers, and students who continue to expand the frontiers of knowledge.

"The next great revolution in science will be driven by the curious minds of today's learners."

SUNDAR PICHAI'S THREE FILTERS

A. Choose optimism

First, choose optimism.

This might not ring true to you at this moment. The world is going through a lot: global conflicts, economic anxiety, a rewiring of technology, information overload, all at a fast pace.

It's easy to look at the news of the day and think that we're living in uniquely challenging times. For me, it's helpful to remember that each generation has faced hardship in their own way. We don't get to choose the world we graduate into; but we do get to choose how we frame our circumstances.

This was something my parents instilled in me at a young age. I grew up in the vibrant city of Chennai, India. It was a comfortable life for the most part, but in those early years we had some challenges. We worried about severe drought and whether the water trucks would arrive in time. And for us technology came slowly. We had to wait years to get a telephone, a tv, a refrigerator. Each changed our lives in meaningful ways.

My parents never let the constraints limit my imagination of what was possible; it's the reason I even let myself dream I could one day work in a far away place called Silicon Valley.

When the call from Stanford came, my father spent the equivalent of a year's salary to buy my ticket. It was my first time on a plane.

When I landed in California, it wasn't exactly as I had imagined. I remember that first drive down 280 coming from the airport with my host family.

If you're not from here, California is advertised as being really lush and green. But when I looked out the window, it was more…brown. I guess I said this out loud, I'm not sure why. My host, Mrs. Jane Earl, gently corrected me. "We prefer to call it golden," she said.

And that's exactly what I mean by choosing optimism. It's about reframing for the positive: Where I saw brown, she saw golden. This slight change of perspective had a huge ripple effect on how I thought about the world around me.

Lush forestry wasn't all that was mis-advertised, if I'm being honest. The ocean looks warm and inviting on the brochure. A Stanford professor even emailed me before I accepted and used the beautiful beaches as a selling point.

So the first time I went to the beach in Santa Cruz, I ran fully into the water. It was not warm.

I've since learned that the Atlantic can be warmer — which, by the way, is the only reason Stanford joining the ACC makes any sense at all.

Despite the brown hills and cold ocean, it seemed like almost everyone I encountered had a generally positive outlook on life. Maybe it's because you can wear shorts all year, I don't know.

I found myself adopting this California optimism. And it helped me navigate one of my bigger pivots during my time at Stanford: I came here fully intending to get my PhD, and to move into academics. Life had other plans, and I needed to get a job sooner. So I left my doctorate program. Stanford was generous to offer me the chance to fulfill the requirements for a master's.

I could have seen it as the end of a dream. But thanks to Mrs. Earl, I was able to see that particular brown hill as golden. In that moment, I chose optimism.

A. Work on hard things

The second filter is to gravitate towards working on hard things.

I'd love to tell you I was an immediate success after leaving Stanford… I wasn't. Even a decade later, I felt like I wasn't on the right path, and it took me a while to find my footing.

Until I applied to Google. I had my final interview there in 2004, it was April Fool's Day and the day Gmail launched. So when my interviewers asked me about it, I wasn't sure if it was a joke or a real product. That's because at the time, one gigabyte of free storage for everyone felt super ambitious, and almost impossible.

A couple years into the job, I got my chance to work on a seemingly impossible problem, too. It was around this time that the internet was moving into a new phase. The web was evolving from simple web pages to rich applications. There was a group of us that felt we could reimagine the browser to be much better and faster, and we had an early prototype that we thought was pretty good.

Internally there was a consensus that building a browser would be incredibly difficult, requiring hundreds of engineers; we had a group of about ten.

The consensus was right. It was going to be really hard. In some ways we were naive, and it's good to be a bit irrational when you approach new things.

And in 2008, we launched what we thought was a great browser. We had eight million users in the first twenty-four hours, and the reviews were really positive. And then user growth stagnated.

After a year, we had around two percent share. I remember Steve Ballmer, the CEO of Microsoft, made fun of Chrome in an interview and called it a rounding error.

It could have been demoralizing. But with that California optimism, I told the team that the fact he went out of his way to dismiss us meant we were doing something right.

We kept going, setting highly aggressive stretch goals to keep the team pushing. We rapidly iterated, shipping the browser every six weeks while others shipped one maybe every six months to a year. Success began to follow.

Working on hard things has taught me a lot: It typically attracts other great and optimistic people. And even if you miss meeting the high goals you set, you'll still achieve something great.

So when you have the choice to work on something hard — say yes.

B. Do what excites you

And the third filter I use: when all else is equal, do the thing that excites you.

For me, that has always been access to technology. The more access my family had, the better our lives got.

I didn't have much access to a computer until I came to Stanford. So you can imagine my surprise when I walked into Sweet Hall and saw rows and rows of computers that I could use anytime I wanted.

It was 1993 and the internet was being built literally all around me. I saw it as a fundamental enabler of human progress. The idea that I could be a part of bringing it to as many people as possible was exciting. It's why I took the offer at Google. And why I jumped at the chance to work on projects like Chromebooks and Android later on.

Several years ago, I remember meeting a group of women in rural India using Android smartphones for the first time to learn new trades and speak with loved ones far away.

And I remember visiting a classroom in Pittsburgh and seeing students from different backgrounds learning through the products I helped to build. Seeing computing change people's lives as it had changed mine was the most exciting thing in the world to me.

So as you look at your own path, don't focus on:

The thing your parents want you to do,

Or the thing all your friends are doing,

Or that society expects of you.

Instead, think about the things that keep you chatting excitedly with your roommates late into the night. And go do those things.

Courtesy : Google CEO blog.

LODHA RESEARCH FOUNDATION UNVEILS THEORETICAL PHYSICS INSTITUTE TO PROMOTE FUNDAMENTAL RESEARCH

The Lodha Foundation has announced the launch of the **Lodha Theoretical Physics Institute (LTPI)**, a privately funded institute that the Foundation says has attracted global talent.

The LTPI, led by **Professor Jainendra Jain**, a recipient of the prestigious **Wolf Prize in Physics**, will encourage bold ideas in fundamental physics. The Foundation said the institute is envisioned as a dedicated centre for fundamental research in theoretical physics in India.

The institute seeks to address the need for sustained, long-term scientific inquiry by creating an academic environment that enables focused research programmes, international conferences, and meaningful collaboration among leading scientists from India and across the world.

"We believe that the pursuit of excellence in everything we do is extremely important to creating the biggest possible impact," said **Abhishek Lodha**, Trustee of the Lodha Foundation and Managing Director & CEO of Lodha Developers.

"Whether it is identifying geniuses from across the country and putting them on accelerated programmes, investing in urban sustainability solutions, or promoting innovation and research through the Lodha Mathematical Sciences Institute and now the LTPI, we want to contribute meaningfully to India's journey towards becoming a developed nation," he said.

The LTPI is founded on the vision that transformative technological eras are preceded by revolutions in the fundamental sciences. It will serve as a dedicated centre for fundamental research in India, attracting outstanding scientific talent from around the world while fostering a culture of intellectual curiosity.

By bringing together exceptional faculty members, postdoctoral fellows, and long-term visiting scholars, the Institute will provide intellectual freedom, stability, a collaborative environment, and the courage to pursue deep scientific questions and bold ideas—enabling discoveries whose impact may unfold over decades.

"The most extraordinary minds from across the world will come together and spend time freely thinking about physics without any encumbrances," said **Ashish Kumar Singh**, Chief Mentor of the Lodha Foundation.

"When extraordinary minds come together, they produce extraordinary results, and this is a bet we are taking for India," he added.

The LTPI will be headed by its Founding Director, **Professor Jainendra K. Jain**, a distinguished theoretical physicist and recipient of both the **Oliver E. Buckley Prize** and the **Wolf Prize in Physics**.

His discovery of emergent particles known as **composite fermions**, and the theory describing them, has profoundly advanced the understanding of correlated quantum matter and continues to shape modern theoretical physics.

"We know that theoretical physics lies at the heart of our understanding of nature. Advances in theoretical physics have historically shaped scientific thought and laid the groundwork for transformative developments across disciplines," Professor Jain said.

"To become a developed nation by 2047, India must build strong institutions with world-class scientific research infrastructure. The LTPI will be an especially significant step in that direction, as it will be the first fully privately funded physics institute in India," he added.

Published on May 28, 2026, at 4:39 p.m. IST.

Ceremonial inauguration of the Lodha Theoretical Physics Institute (LTPI) during the 10th International Meeting on Emergent Phenomena in Quantum Hall Systems (EPQHS-10), Mumbai, on 27 May 2026.
From left: Prof. Jainendra K. Jain (Founding Director, LTPI), Shri Abhishek Lodha (Trustee, Lodha Foundation), Prof. Klaus von Klitzing (Nobel Laureate in Physics, 1985), and Shri Abhay Firodia (Industrialist).

Why Fundamental Research Matters

"Today's curiosity becomes tomorrow's technology."

Many of the technologies we use every day were born from research that initially had **no immediate practical application**.

Fundamental Discovery	Today's Applications
Quantum Mechanics	Computers, smartphones, lasers, MRI
Electromagnetism	Electricity, motors, telecommunications
Relativity	GPS navigation, satellite systems
Nuclear Physics	Nuclear medicine, power generation
Semiconductor Physics	Microchips, AI, modern electronics

MEET SWAMI JNANANANDA: THE MONK WHO BECAME A NUCLEAR SCIENTIST AFTER YEARS OF MEDITATION IN HIMALAYAS

In the early decades of the 20th century, few lives followed a trajectory as unusual as that of **Swami Jnanananda**. Born in Andhra Pradesh, he spent years in spiritual practice across the Himalayas before turning to science, eventually studying physics in Europe, the United Kingdom, and the United States. His work focused on radiation and spectroscopy at a time when nuclear physics was rapidly emerging as a defining field of modern science. After returning to India, he helped build one of the country's early academic centres for nuclear physics at Andhra University, combining scientific institution-building with a philosophical outlook shaped by years of meditation.

Swami Jnanananda's early life and spiritual journey

Born as **Bhupathiraju Lakshminarasimha Raju**, Jnanananda renounced conventional life at a young age and travelled through spiritual centres such as **Rishikesh** and the **Himalayas**. This period of meditation and ascetic discipline is often described as foundational to his later life.

While detailed records are limited, accounts consistently suggest that this phase shaped his intellectual discipline, patience, and ability to engage deeply with complex problems. In many ways, the rigour of scientific research he later pursued mirrors the mental discipline cultivated during this spiritual period. His experiences also influenced his worldview, blending philosophical inquiry with a strong commitment to systematic scientific exploration and lifelong learning.

Turning to science in Europe

Jnanananda's transition from spiritual seeker to scientist began in **Dresden, Germany**, where he studied mathematics and physics. He later moved to **Charles University** in **Prague**, focusing on X-ray physics and spectroscopy.

At the time, X-ray spectroscopy was an important tool in understanding atomic structure, helping scientists analyse how radiation interacts with matter. His work in this area placed him within a broader global effort to understand atomic behaviour, which would later become central to nuclear physics. He earned an advanced research degree in the mid-1930s, marking his formal entry into the scientific community.

Research in the UK and the US

During the Second World War, Jnanananda worked at the **University of Liverpool**, one of the key centres of nuclear research in Britain. The university was closely associated with **James Chadwick**, whose discovery of the neutron had transformed the understanding of atomic structure and made nuclear reactions scientifically accessible.

Jnanananda's research focused on **beta radiation spectroscopy**, a field that studies the energy distribution of electrons emitted during radioactive decay. This work was important for understanding nuclear processes and the properties of unstable isotopes.

He later continued his research at the **University of Michigan** in the United States, where access to advanced laboratory infrastructure allowed further work on radioactive materials and experimental techniques such as **high vacuum systems**. These systems are critical in physics experiments because they minimise interference from air particles, enabling precise measurements of radiation and particle behaviour.

Building nuclear physics in India

After returning to India in **1947**, Jnanananda joined the **National Physical Laboratory** as a senior scientific officer, contributing to the country's early post-independence scientific ecosystem.

In **1954**, he moved to **Andhra University**, where his most significant institutional work began. By **1956**, he had established the **Department of Nuclear Physics**, creating infrastructure at a time when India was still developing its scientific base.

He set up laboratories equipped for radiation studies, introduced experimental training programmes, and mentored students who would go on to contribute to India's scientific landscape. The department's research output and doctoral training helped position the university as an important centre for nuclear physics outside the direct control of the **Department of Atomic Energy**.

Contributions beyond the laboratory

Jnanananda's work was not limited to experimental physics. He is credited with writing on **high vacuum techniques**, an essential component of many physics experiments involving particles and radiation.

At the same time, he engaged deeply with philosophical thought, writing on **Vedanta**, **yoga**, and the relationship between **science and spirituality**. Rather than treating these as separate domains, he approached them as complementary ways of understanding reality, an approach that remains relatively rare even today.

Legacy

Swami Jnanananda's life offers insight into a period when modern science in India was still being built by individuals who combined global training with local institution-building. His journey reflects three important ideas.

First, scientific excellence in India often depended on individuals who trained abroad and returned to build institutions from scratch. Second, early nuclear physics research in India was not limited to government-led programmes but also grew within universities. Third, his life challenges the assumption that scientific inquiry and spiritual practice are inherently separate, showing that both can coexist within a single intellectual framework.

His legacy continues through the institutions he helped shape and the broader idea that curiosity, discipline, and openness to different ways of thinking can lead to unexpected and lasting contributions.

Courtesy: Times of India Science Desk

THE IMPORTANCE OF SKILL LABS IN SCHOOLS

Skill-based education can turn schools into spaces of exploration, innovation, and real-world readiness

Today, it is essential to connect education with practical skills and real-world opportunities. This needs to begin in schools, and introducing skill-based education from Class 6 onwards can play a transformative role in preparing students for the future. Learning must extend beyond the blackboard, as students engage with tools, observe real processes, and gain hands-on experiences. Skill laboratories can focus not only on skill development but also on building confidence, developing practical understanding of classroom concepts, and strengthening overall learning outcomes.

Through creative arts, crafts, nature-based exploration, scientific observation, and community-linked activities, students can meaningfully engage in learning based on their environment, and connect with life forms, machines, materials, and human services. These experiences are aligned with the vision of the National Education Policy (NEP) 2020 and lay a strong foundation for informed career choices and holistic development.

Schools can hold a 10-day bagless period for students from Classes 6 to 8 to encourage internships with local vocational experts such as carpenters, gardeners, potters, and artists. This will create meaningful learning experiences by shifting the focus from textbooks to hands-on exploration, make learning more enjoyable and stress free and boost their curiosity, motivation and self-confidence. Students gain exposure to real work environments, develop an appreciation for different types of work and build essential life skills such as creativity, collaboration, critical thinking and problem-solving. To support those who wish to explore more, schools can offer online vocational modules to build on their experiences in their own time. Additionally, having bagless days dedicated to arts, quizzing, sports, and vocational crafts throughout the year can enrich students.

Schools can also collaborate with local institutions such as ITIs and polytechnics and offer exposure to real vocational practices and broaden learning. To create a safe and supportive environment for such activities, principals must ensure that school facilities are well maintained and fire and safety certificates are obtained regularly. In addition, schools can also ensure that their blogs or websites are updated and easy to navigate so that parents and the community can see what is happening in the school and share their feedback. This helps to keep channels of communication open and builds a stronger connection with the school.

To operate skill labs, schools can:

- Have a designated room and provide infrastructure for group and individual activities.
- Ensure that the electricity connection is available and reliable.
- Ensure that all the essential materials and tools are available.
- Provide computers and Internet connectivity.
- Appoint a teacher who will be the person in charge to manage and monitor the lab.
- Keep the lab open and accessible to students every day.
- Divide students into batches so that while one group uses the skill lab, another can visit the art room or work-experience room.

When used effectively, skill labs can make education more engaging and meaningful, as they equip students with not only technical knowledge but also problem-solving abilities and creativity. These are qualities that are essential for jobs of the future and will help shape responsible, capable, and confident citizens.

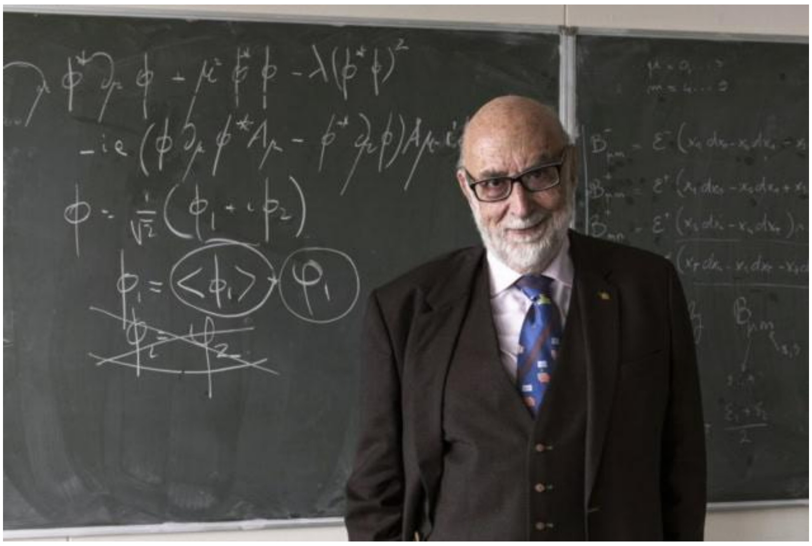
The writer:

J. S. V. Lakshmi
Assistant Commissioner (Retd.), Kendriya Vidyalaya Sangathan, Hyderabad Region.

"The classroom teaches concepts. The skill lab transforms concepts into competence."

Traditional Learning	**Skill Lab Learning**
Memorising facts	Exploring ideas
Listening	Doing
Following instructions	Solving problems
Individual work	Team-based learning
Learning for examinations	Learning for life

BELGIAN NOBEL-PRIZE-WINNING THEORETICAL PHYSICIST FRANÇOIS ENGLERT DIES AGED 93



Particle pioneer François Englert shared the 2013 Nobel Prize for Physics with Peter Higgs for the theoretical work behind the Higgs boson.
(Courtesy: CERN)

The Nobel-prize-winning Belgian theoretical physicist François Englert, whose work led to the discovery of the Higgs boson, died on 18 June at the age of 93.

Englert's studies, which he carried out in the early 1960s with his colleague Robert Brout, demonstrated that fundamental particles can acquire mass by interacting with a field that permeates the universe. The work set in motion a decades-long hunt for the Higgs boson, which was finally discovered at the CERN particle-physics lab near Geneva in 2012.

For the work, Englert shared half of the 2013 Nobel Prize for Physics together with the British theoretical physicist Peter Higgs, who died in 2024.

Early Life

Born in Brussels, Belgium, on 6 November 1932, Englert studied electrical engineering at the Free University of Brussels (ULB) before switching to physics and completing a PhD at the university in 1959.

For two years he then worked at Cornell University before returning to ULB in 1961, where he remained for the rest of his career.

New Particle

"Spontaneous symmetry breaking" is a well-known concept in condensed-matter physics where it had been used to explain how, for example, unordered regions of a magnetic material could suddenly align themselves in a specific direction.

In the early 1960s, the Japanese–American particle physicist Yoichiro Nambu adapted the phenomenon into quantum field theory.

Working at the ULB, Englert and Brout took inspiration from Nambu's work and in 1964 the pair proposed that the weak and electromagnetic interactions could be united by spontaneous symmetry breaking.

Higgs, who independently came to the same conclusion as Brout and Englert, showed that the particles that carried the weak force acquired their mass through interactions with an all-pervasive field, now known as the Higgs field, with the interactions occurring via the Higgs boson.

In 2012, at CERN's Large Hadron Collider, physicists working on the LHC's giant ATLAS and CMS detectors discovered the Higgs boson with a mass of about 125 GeV.

The following year, Englert shared half of the 2013 Nobel Prize in Physics with Higgs "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments".

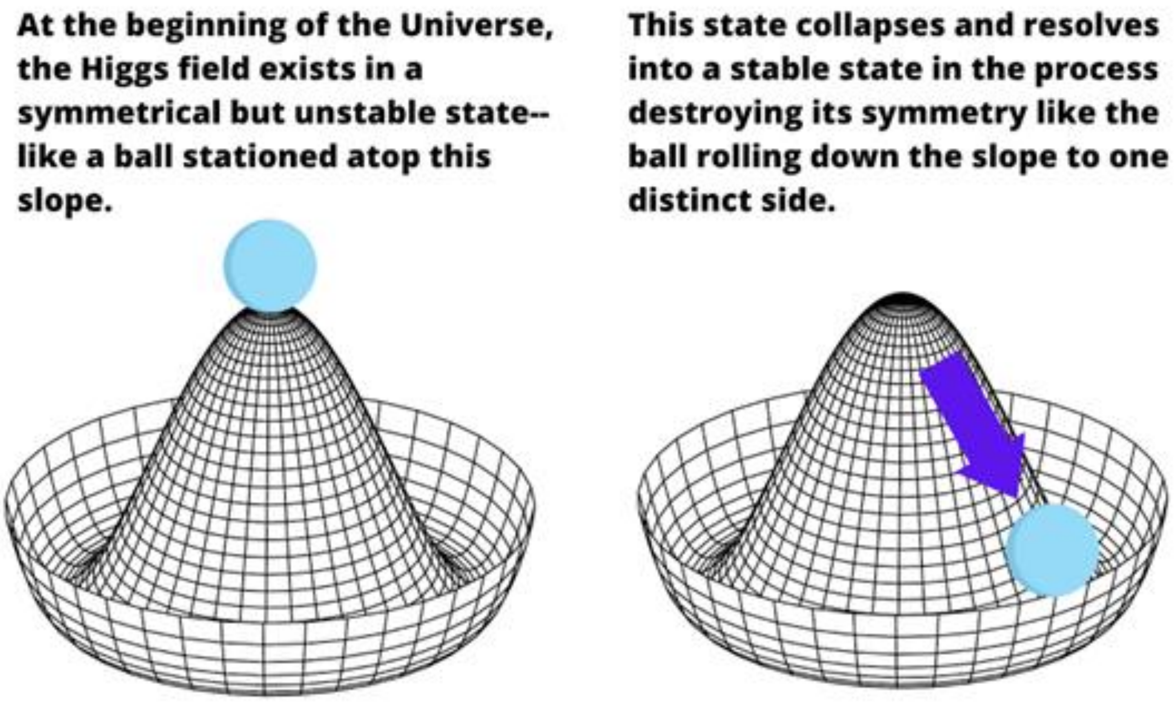
Brout died in 2011, so was not given the Nobel Prize as it is not awarded posthumously.

As well as the Nobel Prize, Englert won many other awards including the Francqui Prize, awarded by the Francqui Foundation in 1982, the Wolf Prize in Physics (2004) and the American Physical Society J. J. Sakurai Prize (2010). In 2013, he was ennobled a Baron by King Albert II of Belgium.

Particle physicist John Ellis from King's College London, who has spent most of his career at CERN, told *Physics World* that he will remember Englert for his "his modest and polite demeanour, despite his evident and justified pride in his ground-breaking work".

"His memory lives on as one of the founders of the Standard Model and an originator of one of its greatest puzzles, the Brout-Englert-Higgs mechanism for breaking symmetries and generating particle masses," adds Ellis. "How long will it be before we understand this remarkable, yet crucial, aspect of Nature?"

Author: Michael Banks, Editor, *Physics World*



THE TEACHING CRISIS BEHIND THE NEET UPROAR

The Decline in Teaching Quality and the Rise of YouTube Educators

The decline in teaching quality and the rise of YouTube educators are not primarily the result of bad teachers. They are the result of policy choices that have weakened the institutional conditions required for good teaching.

A prominent pro-government news anchor on prime-time TV called India's YouTube teachers **"do kaudi ke"** on May 29, a phrase that means "worthless", soon after many prominent teachers spoke up against the NEET-UG 2026 paper leak scandal.

In recent times, the digital education platform has seen a huge growth in numbers and reach. Studies show that India now has **50 million active online learners**, up from **12 million in 2020**. In parallel, there is a significant drop in government school enrolments every year. In only the academic year **2024-25**, almost six lakh students dropped out of government schools, while private schools gained an equal number of students in that period. This significant shift is due to the systemic failure of the public education system. And this is exactly where the problem lies.

The anchor's contempt of YouTube's celebrity "explainer" teachers accidentally highlighted a very real problem, but took aim at the wrong target. Digital teaching does not underline the inadequacies of teachers, but the systematic destruction of the working conditions of teachers at all levels. The introduction of the **National Education Policy (NEP) 2020** has only intensified the problem manifold.

Nor is this a story about students, although students play a key role in it. It is a story about the fate of a teacher's critical pedagogical competence when the institutional structure for which he or she is responsible does not, by design, provide any serious intellectual engagement.

Currently, **NITI Aayog** estimates that more than **35 per cent** of teaching jobs in State universities are lying vacant. In **Rajasthan University** alone, there are unfilled posts of around **400-500** of a total of **800 sanctioned posts**. As per the last available data on **AISHE (All India Survey on Higher Education)** for **2021-22** (the government has not released **2020-21** and **2022-23** AISHE reports yet), several States had **40 to 50 per cent** non-permanent faculty in teaching positions. Ad hoc teachers, guest lecturers, and contractual appointments (CLAs) are paid a fraction of the salaries of permanent jobs and are rarely given health coverage or a pension. Since **2019**, the statutory body for teacher education, the **National Council for Teacher Education (NCTE)**, has not appointed any permanent members.

This is not an anomaly. This is a structural issue, and **NEP 2020** is powerless to change it. The NEP aspires for the **Gross Enrolment Ratio (GER)** to be increased to **50 per cent by 2035**, but provides no direction on how to do it. What happens, instead, is that institutions keep adding students and contract teachers, who come cheap and can be fired with impunity.

The precarity of contractual teachers is not just a welfare issue; it is a pedagogical one. An adjunct instructor who has no idea of whether or not she will be rehired next semester cannot afford to take intellectual risks when teaching in a classroom. The curriculum given to her cannot be challenged. She will never be able to develop the long-term pedagogical connections that critical thinking really demands. But that is exactly the workforce that India's booming higher education system is being built upon—employees who are easily exploited and who are limited by the material conditions of their existence.

The Paperwork Republic

There is also the issue of administrative loads. Today, faculty in higher education operate at the behest of **NAAC** parameters and under the shadow of **NEP's performance metrics**. A significant portion of higher education work has been turned into documentation work. Outcome-based education models don't really care about classroom performance and are focussed on course-by-course results. They are more interested in the number of weeks completed at the end of a semester, in the form of self-appraisal forms, portfolios, accreditation audits, and mandatory faculty development programmes. Teachers also regularly perform non-academic duties like census enumeration, election deployment, and disaster survey. All these are not accidental diversions; they are deliberate.

This is complicated by the examination machine. The NEP's passion for continuous assessment and multiple entry-exit was supposed to indicate that it wanted to move away from terminal examination. But in practice, it has created many more overload assessments. There are more assignments, more internal assessments, more grade reports, and more administrative hassles that come along with each assignment. And with this, the concept of the exam as a sorting mechanism has not changed at all. What was supposed to be an educationist's dream has turned into a bureaucratic grind. The teacher who truly hopes to lead a "Socratic" seminar or to send students a book that will cause them to think more than to agree is set against the institutional tide of an assessment culture that values measurable products more than thinking processes.

Privatisation by Design

When it comes to privatisation, the NEP is not as clear as it likes to appear in its words. According to **AISHE 2020-21** data, already **two-thirds** of the higher education institutions in India are under private management. The **Board of Governors** model of institutional autonomy was supposedly intended to make it easier for those running public universities to avoid government policy or interference. But this allowed a backdoor entry for corporate governance, in which job allocation is subservient to accountancy. This implies increased contract hires, the flattening of pay lines, and teaching loads based on enrollment. The commitment to spending **6 per cent of GDP** on education still has a long way to go, as budget allocations for education are at **4.6 per cent of GDP**. The gap between promise and allocation is filled by privatisation.

The numbers tell the rest. The **Department of Higher Education's** allocation in the Union Budget fell from **2.52 per cent** in **2013-14** to a mere **0.91 per cent** (over **55 per cent lower**) by **2024-25**. Higher education now only receives **0.7-0.8 per cent of GDP**. The financial responsibility for education has been insidiously transferred from the State to families, and **75 per cent** of higher education is now privately operated.

This is not an abstraction in a classroom. When an institution's existence is dependent more on revenue through fees than State funding, the teacher ceases to be an intellectual worker. Now the teacher is a service provider, and the student is a paying customer. Teaching becomes a profession that is less about real "teaching" than about managing expectations. Pedagogy is subordinated to satisfaction. Teaching that makes students go beyond the textbook, to think critically, or one that demands sustained effort from them, is precisely what market-oriented institutions cannot easily afford.

Sociological literature on commodified education has explained that when the "exchange value" displaces the "use value" in the organisation of learning, critical thought becomes an obstacle to be avoided rather than an objective to be pursued. A contractual teacher working in such an institution with no job security is even less able to resist this logic.

Knowledge and Its Gatekeepers

Decolonisation of our educational pedagogy is a rightful demand. The focus of **NEP** on **Indian Knowledge Systems (IKS)** has genuine intellectual possibilities in that direction. But it cannot be treated as a symbolic gesture only. In most institutional settings, IKS integration in practice has been used as a method to reward people with ideological affinity. The **UGC** is working towards the development of a **NET** component and syllabus for IKS and faculty development modules. This is a particular cultural-nationalist version of "knowledge". Therefore, the ability to act with affinity has become, informally, a credential in this climate. A very different institutional environment for teachers in critical theory, constitutional history, or materialist social science existed a decade ago.

All of this has created an abnormal centralisation. The **Central Advisory Board of Education** used to work as a forum of federal deliberation on matters of education. Its role is now largely ignored. The **UGC**, now under NEP, has complete control over curriculum and assessment structures, credit frameworks, and institutional autonomy. States with other pedagogies, other languages of instruction, and other mixes of students are expected to follow a framework set by others entirely alien to them. The regional teachers are part of a policy they did not participate in developing. They cannot challenge any of it; they are instructed only to enforce it.

Back to that TV anchor, whose comment showed a genuine class bias. It is directed against teachers who are generally from the same aspirational, under-resourced publics whom they now teach. There might be some truth in her grievances about declining teaching standards. Still, the reason YouTube teachers are here is that the formal classroom has been emptied of resources, of intellectual freedom, of institutional support to the point that the students have been forced to seek all of it elsewhere. It is the government's policy decisions that are responsible for the institutional decay in education that the country is facing.

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The Power of a Teacher

A student once asked his physics teacher,

"Sir, will this chapter come in the examination?"

The teacher smiled and replied,

"Perhaps. But a better question is—will this chapter help you understand the world?"

Years later, the student became an engineer. He often said that while he had forgotten many examination questions, he never forgot his teacher's answer. It changed the way he learned—not for marks, but for understanding.

Moral: *Great teachers prepare students not just for examinations, but for life.*

Artificial Intelligence (AI) in Physics Education

Artificial Intelligence (AI) is reshaping how students learn, teachers teach, and schools operate. In physics education, this change is even more noticeable. AI in Physics Education is no longer a futuristic concept—it's happening right now in classrooms and online learning platforms. From simplifying complex theories like quantum mechanics to generating instant feedback on problem sets, AI tools are becoming powerful study partners for students. However, with these benefits come real challenges: academic integrity, over-dependence, and fairness in assessment.

The Role of AI in Modern Physics Classrooms

1. Understanding How AI Enhances Physics Learning

AI in Physics Education has redefined how students interact with scientific content. AI-driven tutoring systems can explain complex concepts like electromagnetism or relativity in simple, conversational ways. Instead of memorizing equations, students can ask AI questions, visualize simulations, and explore "what if" scenarios in real time.

Students benefit from instant explanations of problems, personalized study plans, and targeted practice exercises. These AI tools adapt to each learner's pace—something traditional classrooms often can't manage. For example, if a student struggles with Newton's laws, the AI can focus on force and motion until mastery is achieved. This flexibility helps students gain confidence and stay motivated.

2. Personalized Learning and Adaptive Feedback

AI systems use algorithms that track performance and adapt lessons accordingly. If a student repeatedly struggles with vector diagrams or energy conservation, the AI adjusts the difficulty level and provides additional examples.

Unlike one-size-fits-all teaching, AI makes learning more customized. It also gives real-time feedback, so students know where they went wrong and how to improve. For teachers, these insights highlight individual strengths and weaknesses, helping them design better lesson plans. Personalized AI support ensures no student is left behind.

Advantages of Using AI in Physics Education

1. Simplifying Complex Concepts

Physics is filled with abstract ideas—wave-particle duality, relativity, quantum theory—that often confuse students. AI can break these concepts into digestible steps using examples, visuals, and analogies.

For instance, AI platforms can simulate experiments like the double-slit experiment or magnetic field lines, making abstract topics tangible. This visual and interactive approach enhances comprehension and memory retention. Students no longer need to rely solely on textbooks—they can "see" physics in action.

2. Access to Instant Support and Practice

AI in Physics Education allows students to get help anytime, anywhere. No more waiting until the next class or tutoring session. AI chatbots and digital tutors can solve numerical problems, explain formulas, and even generate new practice questions.

This accessibility keeps learning continuous. AI-driven systems can also offer step-by-step solutions, enabling students to understand the "how" and "why" behind each answer. Over time, this promotes self-directed learning and reduces dependency on traditional homework assistance.

3. Boosting Engagement and Motivation

Gamified AI learning platforms turn problem-solving into a rewarding experience. Students earn points, badges, or progress bars as they master physics challenges.

When students are engaged, retention rates increase. AI tools use gamified quizzes, progress tracking, and interactive challenges to turn learning into an active process rather than passive reading. This encourages curiosity and continuous exploration—key traits for future scientists.

Challenges and Ethical Concerns in AI-Based Learning

1. The Risk of Over-Dependence on AI

While AI can make learning easier, it can also make students overly reliant on it. If learners use AI just to find answers without understanding the process, they lose critical thinking and problem-solving skills.

This "copy-paste" mentality can stunt intellectual growth. Students must remember that AI is a tool, not a teacher replacement. Educators and parents should encourage active engagement—using AI to clarify doubts, not complete assignments.

2. Academic Integrity and Fair Assessment

One major challenge of AI in Physics Education is maintaining academic integrity. Since AI tools like ChatGPT can solve advanced problems or write essays, distinguishing between genuine student work and AI-generated answers becomes difficult.

Schools must adopt AI-detection tools and redesign assessments to focus on creativity and reasoning rather than rote solutions. Supervised exams and project-based learning ensure that students demonstrate real understanding rather than relying on AI's computational abilities.

3. Inaccuracy and Misleading Responses

AI tools aren't perfect. They sometimes provide incorrect or incomplete explanations, especially in multi-step physics problems. Students might believe incorrect outputs, which can create misconceptions.

It's crucial that students verify AI's answers with textbooks, lectures, and verified sources. Teachers should train students to question and validate results—building digital literacy and scientific reasoning.

Integrating AI Responsibly in Physics Education

1. Teaching Students How to Use AI Effectively

Schools should teach AI literacy—how to use AI tools responsibly and recognize their limitations. This means showing students when to trust AI explanations and when to rely on logic and manual problem-solving.

Classroom discussions about AI's strengths and weaknesses help build awareness. Teachers can include AI-related mini-projects that involve evaluating AI accuracy, encouraging students to think critically and verify results.

2. Redesigning Assessments for Real Learning

To reduce misuse, schools can shift toward creative and analytical tasks that AI cannot easily complete. For instance, experiments, data interpretation, and real-world problem-solving tasks emphasize thinking over repetition.

Hands-on experiments, physics modeling, and open-ended projects promote innovation. These methods not only measure comprehension but also inspire curiosity—something AI can't replicate.

3. Collaboration Between Teachers and AI Tools

AI should complement, not compete with, educators. When teachers use AI as an assistant—for generating quizzes, tracking performance, or explaining alternate methods—it saves time and personalizes instruction.

The teacher's emotional intelligence and mentorship remain irreplaceable. AI can't motivate, empathize, or adapt to individual emotions—but it can help teachers focus more on nurturing creativity and understanding.

The Role of Parents in Guiding AI-Based Learning

1. Encouraging Independent Thinking

Parents play a vital role in helping students develop critical thinking. They should encourage their children to solve problems first, then use AI to verify or refine their understanding.

This builds resilience and curiosity. AI should be a support system—not the first or only solution. Parents can ask children to explain physics problems aloud, helping reinforce concepts.

2. Monitoring AI Use at Home

Parents should set boundaries for when and how AI can be used for homework. Checking AI-generated answers against class notes or textbooks teaches accountability and accuracy.

This not only ensures academic honesty but also turns homework into collaborative learning. Parents can ask open-ended questions like "Why does this answer make sense?" to promote deeper understanding.

3. Fostering Balanced Tech Habits

While AI is a powerful learning aid, balance is key. Excessive screen time and reliance on technology can affect focus. Parents should encourage offline study time, group discussions, and hands-on experiments.

Developing discipline around AI use helps children grow into thoughtful learners who value both technology and independent thinking.

Discover Learning Tutors' Approach to AI in Education

At Discover Learning Tutors, we understand the evolving landscape of education. Our tutors teach students how to use AI in Physics Education effectively and responsibly. We integrate AI tools into lesson plans to enhance comprehension but emphasize that genuine learning happens through engagement, discussion, and practice.

Our tutors encourage students to use AI as a supplemental study partner—not as a replacement for effort. By combining expert human instruction with smart AI support, we help learners grasp core physics principles, develop analytical thinking, and build long-term confidence.

Conclusion: Building a Smarter, Ethical Future with AI in Physics Education

The rise of AI in Physics Education brings immense opportunities along with genuine challenges. When used wisely, AI simplifies learning, personalizes feedback, and nurtures curiosity. However, unchecked reliance can weaken understanding and integrity.

Schools, parents, and tutors must work together to guide students in balancing AI support with real intellectual effort. At Discover Learning Tutors, we champion responsible AI integration—where technology enhances learning, not replaces it. By combining human insight with AI innovation, we can create a generation of learners who truly understand the science behind the systems shaping their world.

FAQs on AI in Physics Education

1. Can AI completely replace physics teachers?
No. AI can assist by offering quick explanations and practice, but it lacks the emotional intelligence, creativity, and mentorship that human teachers provide.

2. How does AI improve physics learning outcomes?
AI provides instant feedback, personalized study plans, and interactive simulations that make complex physics concepts easier to understand and remember.

3. What are the risks of using AI for homework help?
Over-reliance on AI can reduce problem-solving ability and promote academic dishonesty. Students must use it to learn, not to shortcut their work.

4. Are AI answers always accurate in physics?
Not always. AI sometimes produces incorrect or incomplete solutions. Students should verify AI-generated results with textbooks and teachers.

5. How can schools and parents ensure responsible AI use?
By teaching AI literacy, supervising usage, promoting critical thinking, and encouraging hands-on assessments that AI can't complete on its own.

Courtesy: *Discover Learning Tutors*
Dubai, UAE

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Physics Smile Corner

Newton's Discovery

A student asked,
"Sir, how did Newton discover gravity?"
Teacher:
"He kept his eyes open when the apple fell."
Student:
"If he had been using his mobile phone, we might still be searching for gravity!"

Artificial Intelligence

Teacher:

"Can AI replace teachers?"

Student:

"No, Sir."

Teacher:

"Why?"

Student:

"Because AI can answer questions, but only teachers know which questions to ask."

HUMANITY HAS PUMPED SO MUCH GROUNDWATER THAT IT SHIFTED THE EARTH'S AXIS

On June 15, 2023, a study published in the scientific journal *Geophysical Research Letters*, by the American Geophysical Union, presented a conclusion that caught the attention of the global scientific community: human groundwater withdrawal between 1993 and 2010 was intense enough to redistribute mass on the planet and shift the Earth's rotational pole by almost 80 centimeters to the east.

Led by Ki-Weon Seo of Seoul National University, the work estimated that aquifer pumping contributed to a drift of approximately 4.36 centimeters per year in polar motion, demonstrating that the exploitation of underground water is no longer just a water issue and has also begun to appear in the planet's physical calculations.

The strongest data point is the volume: researchers worked with the estimate of **2,150 gigatons** of groundwater withdrawn from the subsurface during the period, a quantity associated with a rise of more than **6 millimeters** in global sea level.

When pumped from continental aquifers and, in part, redistributed to the oceans, this mass of water slightly altered Earth's balance, like a displaced weight on a rotating body. The study does not indicate a risk of changes in the seasons, but it shows that a daily human activity—irrigation, supply, and water extraction—is already measurable even in the planet's movement.

Study Links Groundwater Extraction to Earth's Pole Displacement

The research analyzed the relationship between water mass redistribution and polar motion. Earth's axis of rotation is not completely fixed. Small changes in the planet's mass distribution can slightly alter the position of the geographic poles over time.

This phenomenon had previously been observed in relation to glacier melt and oceanic redistribution.

The new study showed that groundwater pumping also exerts a measurable influence on this process. According to the authors, intense groundwater withdrawal ended up displacing the Earth's poles by about **4.36 centimeters per year** between 1993 and 2010.

Approximately 2,150 Gigatons of Water Were Removed from the Subsurface

Researchers estimated that approximately **2,150 gigatons** of groundwater were pumped during this 17-year period. Much of this volume was used for agricultural irrigation, urban supply, and industrial activities.

When this water is withdrawn from the subsurface, it eventually evaporates, is consumed, or reaches the oceans via rivers and atmospheric systems.

This alters the global distribution of the planet's water mass, slightly changing Earth's physical balance.

Groundwater Functions as Distributed Mass Within Continents

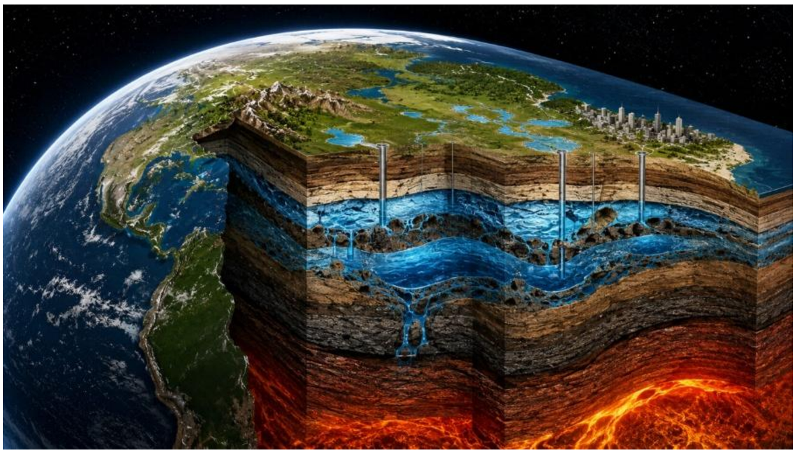
Underground aquifers store enormous volumes of water beneath continents and sedimentary basins. When this water remains trapped in the subsurface, it is part of the natural distribution of terrestrial mass.

When withdrawn and transferred to oceans and the atmosphere, a physical redistribution occurs on a planetary scale.

Although the individual effect of each well is insignificant, the total volume pumped by humanity over decades has become large enough to produce measurable consequences. The study shows that human water exploitation has begun to operate on a global geophysical scale.

Polar Movement Does Not Mean the Planet Is "Tipping Over"

Researchers emphasize that the detected displacement does not represent a risk of catastrophic planetary inversion or abrupt changes in Earth's rotation.



The phenomenon involves small changes in the position of the axis relative to the surface. These movements are part of Earth's natural dynamics but can be influenced by mass redistributions.

Polar changes also occur due to giant earthquakes, ice melt, and ocean circulation. The study's unique contribution is showing that human activities related to groundwater now also participate in this process.

Pumping Contributed to Global Sea Level Rise

In addition to polar displacement, researchers calculated that extracted groundwater raised the global sea level by approximately **6 millimeters** between 1993 and 2010.

Although the number seems small, it represents a relevant contribution within the context of global ocean rise.

Much of the discussion about sea level rise usually focuses on glacier melt and thermal expansion of the oceans.

The study shows that pumped groundwater also participates in this process. This means that depleted aquifers end up directly influencing the global ocean.

Irrigated Agriculture Appears Among the Main Drivers of the Problem

Most of the groundwater extracted on the planet is used for agriculture. Intensive agricultural regions rely heavily on aquifers for irrigation, especially in arid areas or those subject to prolonged droughts.

Countries with highly irrigated agriculture pump enormous underground volumes daily. Over time, some aquifers suffer severe drawdown and permanent loss of storage capacity.

The study reinforces that the global water crisis involves not only water scarcity but also the physical redistribution of planetary mass.

Scientists Were Able to Measure the Effect Using Advanced Geophysical Models

To perform the analysis, researchers combined hydrological data, geophysical models, and observations of Earth's polar motion.

They compared simulations of Earth without groundwater pumping with scenarios that included water redistribution caused by human activity.

The results showed that the models could only correctly reproduce the observed displacement when groundwater withdrawal was incorporated.

This strengthened the evidence that human pumping played a real and measurable role in polar motion.

Mass Redistribution Influences the Planet's Physical Balance

Earth functions as a rotational system sensitive to the distribution of mass on its surface and interior. Significant changes in ice, oceans, or continental water can slightly alter the rotational dynamics.

Similar phenomena have already been observed after gigantic earthquakes, such as the 2011 one in Japan. In the case of groundwater, the difference is that the process occurs slowly, accumulating effects over decades.

The research shows how seemingly local human actions can produce physical consequences on a planetary scale.

Beyond the geophysical implications, the study reinforces growing concern about aquifer depletion. Various regions of the planet already face land subsidence, permanent reduction of reserves, and underground salinization due to excessive pumping.

In some locations, the natural recharge of aquifers occurs much more slowly than human withdrawal. This means that some of the groundwater currently exploited could take centuries to be naturally replenished.

Study Expands Debate on Human Impact on the Earth System

In recent decades, scientists have begun discussing the concept of the **Anthropocene**, a period in which human activities started to alter planetary processes on a large scale.

The new study adds another element to this debate: the human capacity to influence even the mass distribution responsible for Earth's rotational dynamics.

Although the effect is small in absolute terms, it symbolizes the scale of human intervention on the modern planet. Pumping water from underground is no longer just a local supply issue and has become part of global physical transformations.

Given studies like this, do you believe humanity has already crossed invisible limits of intervention in the Earth system, or will technological advancements still be able to reduce these impacts without compromising supply and agriculture?

Written by: Valdemar Medeiros
Science and Technology

The Boy and the Starfish

A man was walking along a beach after a storm and saw thousands of starfish washed ashore. A young boy was picking them up one by one and throwing them back into the sea.

The man smiled and said,

"There are thousands of them. You can't possibly make a difference."

The boy picked up another starfish, gently tossed it into the water, and replied,

"It made a difference to this one."

Message:
Every drop of water saved, every tree planted, and every effort to recharge groundwater may seem small—but together, they make a profound difference.

REACTIONS TO EPR'S PAPER

Taking the EPR paper's title itself, Edward U Condon commented,

" Of course, a great deal of the argument hinges on just what meaning is to be attached to the word 'reality' in connection with Physics ."

Pauli was pretty annoyed. In a letter to Heisenberg he wrote, " Once again Einstein has expressed his views on quantum mechanics. As we know, each time this happens, it is a catastrophe, and this time not in the best of the company either ".

Soon after the EPR paper was published, Rosen was to visit Kharkov (a city in the Soviet Union where Landau was working). The story goes as,

" As Rosen entered Landau's office, Landau jumped up at the sight of Rosen and shouted " How could Einstein have written such a stupid thing !"

But obviously it was Niels Bohr who was to stand up to the veritable challenges that EPR paper had projected.

Of course he did face every bit of it, and he did it in style. But it took nearly a long long six months duration for Bohr and his colleagues to build their defence successfully and shield their side of views against the EPR onslaught. It was then that Bohr brought forward his exotic view of what is termed as **' Collapse of the Wavefunction '.**

The arguments in EPR' paper's based on **' ENTANGLEMENT '** and the rebuttal offered by Bohr based on **' Collapse of the wavefunction '** are two strong pillars that support Quantum Communication.

Though Einstein agreed to Bohr's argument, he never relinquished his position that,

"*Quantum theory is not complete and a more complete theory must be possible*."

Interestingly, though the term EPR paradox has become well known later, Einstein & his colleagues do not talk of any paradox in their paper. However, the term 'paradox' was first used by Einstein in a letter to Schrodinger who picked it up and started referring to the arguments in the EPR paper as EPR paradox and thus the name got struck to get recognised in Physics literature.

Schrodinger shared Einstein's view in the EPR paper that Qu Mechs is not complete. It was in this context that he pushed forward his much publicised working model known as **'*Schrodinger's cat*'.**

Even this proposal is made use of in Qu. Comptng, in defining certain states in a Qu. Mechl system.

In continuation of his conviction that Qm Mechs is not complete, Einstein buttressed his arguments by saying, "*The Old One does not play dice" (God does not play dice*). Bohr replied,

"*Indeed it is no business of ours to tell God how he must govern this world*."

The year before the year he died, Einstein said,

"*I must seem like an ostrich who forever buries his head in the relativistic sands in order not to face the evil quanta*." That attitude continued till the end of his life.

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SCIENTISTS CREATE TINY CHIP THAT USES LIGHT INSTEAD OF ELECTRICITY TO PROCESS INFORMATION

Researchers have created a compact chip that manipulates light-based quantum information with remarkable precision, advancing the development of next-generation photonic and quantum technologies.

What if computers could process information using light instead of electricity? Researchers at Monash University say they have taken an important step toward that future with a tiny new chip that can generate, control, and read light-based signals all in one device.

The breakthrough centers on an emerging field known as "valleytronics," which aims to store and process information using quantum properties inside advanced materials. Scientists have long viewed the technology as a possible path toward faster computing, lower energy use, and more powerful communication systems. But one major challenge has held the field back: no one had successfully combined all the key functions into a single compact platform.

The Monash team says it has now solved that problem.

In a study published in *Nature Photonics*, researchers demonstrated a nanoscale circuit capable of creating specialized light signals, directing them with precision, and converting them into electrical signals on the same chip. The device uses the "valley degree of freedom," a quantum property found in certain materials that can encode information in ways conventional electronics cannot.

Unlike traditional computer chips that rely on moving electrons through circuits, photonic systems use light to carry data. Because light can travel faster and generate less heat, researchers believe future photonic technologies could dramatically improve processing speeds while reducing energy demands in data centers, AI systems, and communication networks.

Lead author **Dr. Chi Li** said the new platform overcomes a major obstacle in valleytronics research.

"Until now, we could generate or detect these signals, but not do everything in one integrated device," Dr. Li said.

"What we've built is a complete on-chip system that can create, route and read this information with very high precision."

Ultra-Thin Materials Enable New Capabilities

The technology combines ultra-thin materials that are only a few atoms thick with engineered nanostructures known as metasurfaces, which can manipulate light at scales smaller than the width of a human hair.

Co-first author **Dr. Kaijian Xing** explained that the team used a layered stacking method to combine these materials without damaging their delicate structure, an issue that has complicated previous attempts to build practical valleytronic devices.

"We employ a straightforward stacking approach to integrate ultra-thin materials with metasurfaces, overcoming the technical challenges of direct material growth on photonic structures, and enabling further advances in valleytronics," Dr. Xing said.

One of the most important aspects of the system is that it operates at room temperature. Many experimental quantum technologies require extremely cold environments to function, often using complex and expensive cooling equipment. By avoiding those conditions, the Monash device becomes far more practical for real-world applications.

The chip also demonstrates a level of miniaturization that could help future technologies move out of research laboratories and into commercial devices.

Why Light-Based Computing Matters

Senior author **Dr. Haoran Ren**, ARC Future Fellow and leader of the Monash NanoMeta Group, said the research could help enable a new generation of compact and programmable photonic technologies.

"This is a significant step toward scalable, chip-based technologies that use light instead of electricity to process information," Dr. Ren said.

"Photonic devices use light to achieve massive bandwidths, ultra-fast data transmission speeds, and lower energy consumption, so what we have achieved has strong potential for applications in quantum computing, advanced imaging, and next-generation optical communication systems."

To demonstrate the chip's capabilities, the researchers encoded and processed two separate images simultaneously, showing that the system can manage multiple streams of information at the same time.

Professor **Stefan A. Maier**, head of the School of Physics and Astronomy and the Nanophotonics Laboratory at Monash, said the work represents an important step toward turning valleytronics into practical technology.

"This is an important step toward fully integrated valleytronic systems," Professor Maier said. "By combining light and quantum materials on a chip, we can access new ways of encoding and processing information."

Reference

"An on-chip programmable valley optoelectronic nanocircuit" by Chi Li, Kaijian Xing, Wenhao Zhai, Luca Sortino, Andreas Tittl, Igor Aharonovich, Michael S. Fuhrer, Kenji Watanabe, Takashi Taniguchi, Qingdong Ou, Zhaogang Dong, Stefan A. Maier and Haoran Ren, **25 May 2026**, *Nature Photonics*.

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The Race Between Light and Electricity

A student asked,

"Why are scientists trying to replace electricity with light inside computer chips?"

The professor smiled and replied,

"Imagine two couriers delivering messages. One travels through crowded city streets, stop at every traffic signal. The other flies directly across the sky."

The student nodded.

"Electrons are like the first courier. Photons are like the second. The future belongs to t who can travel faster with less delay."

WHITE DWARFS – HISTORY, STRUCTURE, PROPERTIES AND APPLICATIONS

White dwarfs are the ultra-dense, Earth-sized corpses of low-to-medium-mass stars. They are supported against gravitational collapse not by the usual thermal pressure, but by the electron degeneracy pressure—a strictly quantum mechanical effect where the Pauli Exclusion Principle prevents electrons from occupying the same space, thereby creating immense outward pressure. They might very well be called 'quantum stars'. Their study in the early part of the last century lead to the acceptance by astronomers of even more compact stars like 'neutron stars' and 'black holes'. Besides providing nature's labs for studying physics at extreme conditions, white dwarfs have helped astronomers in building cosmological models.

History of White Dwarfs

The history of white dwarfs spans more than two centuries, evolving from a visual puzzle that baffled astronomers to a discovery that required the application of quantum mechanics to explain their unusual properties.

Early astronomers observed white dwarfs without understanding what they were looking at, as their immense density contradicted the physics of the time.

1783: William Herschel became the first person to observe a white dwarf—40 Eridani B—noticing it as a faint, dusky star, but he did not realize its unique nature.

1844: German astronomer Friedrich Bessel noticed a slight wobble in the path of Sirius, the brightest star in the night sky. He deduced it was being tugged by an invisible but orbital companion. He was not able to observe the companion.

1862: While testing a new 18.5-inch refracting telescope, American telescope maker Alvan Graham Clark visually spotted this small and mysterious companion to Sirius which was named Sirius B.

The Spectroscopic Paradox

In the early 20th century, technology advanced enough to analyze the light coming from these faint stars, triggering a massive crisis in astrophysics.

1910: Henry Norris Russell, Edward Charles Pickering, and Williamina Fleming analyzed the spectrum of 40 Eridani B. They were shocked to find it was a hot, white spectral type A star even though it was faint - an unexpected combination.

1914: Walter Adams confirmed the same hot, white spectrum for Sirius B.

This created a paradox. A hot star should be massive and brilliant. For Sirius B to be incredibly hot yet 10,000 times fainter than Sirius A, it had to be tiny—roughly the size of Earth. However, calculations showed it contained the mass of the Sun. This meant its density was millions of times greater than anything on Earth, a concept scientists of the era declared physically impossible.

Structure of White Dwarfs

Solving the mystery of their stability required entirely new physics.

1922: Dutch-American astronomer Willem Luyten officially coined the term "white dwarf" to classify these bizarre, faint but hot stars.

1926: British physicist Ralph Fowler solved the density puzzle by applying the newly developed principles of quantum mechanics. He realized that at such extreme densities, Fermi-Dirac statistics apply, and electron degeneracy pressure is what holds the star up against gravity.

1930: At just 20 years old, Indian astrophysicist Subrahmanyan Chandrasekhar calculated that this quantum pressure had a limit. He proved that if a white dwarf exceeded 1.4 solar masses, it would collapse further, a discovery that eventually earned him the 1983 Nobel Prize in Physics.

Electron Degeneracy Pressure

Unlike normal stars, which are held up by the thermal expansion of hot gas, white dwarfs are cold, dead cores. As gravity compresses the star's mass—roughly equivalent to the Sun's mass squeezed into a sphere the size of Earth—the electrons are forced into incredibly close proximity. According to the Pauli Exclusion Principle, no two electrons can occupy the same quantum state. This forces the electrons to move at increasingly high speeds to maintain distinct states. The resulting momentum generates a powerful outward "degeneracy pressure" that permanently halts gravitational collapse.

The Mass-Radius Relation

White dwarfs exhibit a highly counter-intuitive property: they get smaller as they get more massive. Because the electron gas is degenerate, adding more mass increases the star's gravity, compressing it into a tighter radius. This relationship is defined mathematically as **$M R^3$ = constant**, for low mass white dwarfs.

The Chandrasekhar Limit

This bizarre inverse relationship cannot continue indefinitely. As the white dwarf gains mass, the electrons are compressed so tightly that their speeds approach the speed of light—they become relativistic. Once the star's mass reaches approximately 1.4 times the mass of the Sun (the Chandrasekhar limit), the electrons' degeneracy pressure can no longer overcome gravity. Any star exceeding this mass will undergo further catastrophic collapse into a neutron star or a black hole.

Cooling and Crystallization

White dwarfs have no internal nuclear fuel; they shine entirely by radiating away their residual thermal energy. Over billions of years, the star gradually cools, causing the electrons and ions to form a rigid, crystalline lattice structure. Because of this, white dwarfs act more like giant, slowly cooling diamonds in space, eventually fading into invisible "black dwarfs."

Modern Observations

By 1950, astronomers had discovered roughly 100 white dwarfs. In the 21st century, automated sky surveys like the Sloan Digital Sky Survey (SDSS) blew the catalog wide open, identifying tens of thousands of them across the Milky Way. Today, space telescopes use these dead stars as cosmic clocks to measure the precise age of our galaxy.

Astronomers have shifted from discovering isolated, puzzling white dwarfs to compiling massive databases containing hundreds of thousands of these stellar remnants. Modern telescopes can directly observe their compositions, temperatures, and surrounding planetary debris.

Notable White Dwarfs

Sirius B: At just 8.6 light-years away, it is the closest and most famous white dwarf to Earth. Even at its maximum orbital separation from its parent star, Sirius A, observing it is notoriously difficult due to the blinding glare of the primary star.

40 Eridani B: Located 16.25 light-years away, it is part of a triple star system. It is the easiest white dwarf for amateur astronomers to view using standard backyard telescopes.

Janus (ZTF J203349.8+322901.1): Discovered by the Zwicky Transient Facility, this unique, "two-faced" white dwarf is entirely made of hydrogen on one side and helium on the other.

WD 1856+534: A highly intact, Jupiter-sized gas giant planet was observed transiting directly around this white dwarf, proving that some planets can survive the violent death of their parent star.

GD 61: Observed by the Hubble Space Telescope, this "polluted" white dwarf is actively tearing apart and swallowing a massive, water-rich asteroid, offering a glimpse into the chemical makeup of dead alien solar systems.

Rotating White Dwarfs

Rotating white dwarfs introduce complex dynamical and structural shifts that alter the fundamental limits of stellar physics. While a typical isolated white dwarf rotates slowly—taking days or even weeks to complete a single spin—binary interactions and cosmic mergers can spin these ultra-dense remnants up to extreme, relativistic velocities.

The structural physics, behavioural anomalies, and extreme modern examples of rotating white dwarfs include:

The classical Chandrasekhar limit dictating a maximum mass of 1.44 solar masses assumes a perfectly spherical, non-rotating star.

Centrifugal Support: High-velocity rotation introduces strong outward centrifugal forces. This counteracts a portion of the star's gravity, easing the burden on internal electron degeneracy pressure.

Super-Chandrasekhar Masses: If a white dwarf undergoes differential rotation (where the inner core spins faster than the surface), its theoretical maximum stable mass increases significantly. Models suggest these rapidly spinning variants can survive up to 2.0 or more solar masses before collapsing.

Because white dwarfs are intensely dense, extreme spinning alters their physical geometry.

At equatorial rotation speeds surpassing thousands of km per second, the equator bulges outward while the poles flatten. This makes the star highly oblate (pumpkin-shaped). This geometrical distortion fundamentally shifts the internal density profile, altering how the star cools and crystallizes over time.

White Dwarf Interiors

The internal structure of a white dwarf resembles a layered cosmic jawbreaker, completely segregated by atomic weight due to intense gravitational settling. Because there are no fusion reactions to mix the material, heavy elements sink to the center while lighter elements float to the surface. The interior consists of three main structural zones:

The Degenerate Core (99% of the Mass)

The vast majority of a white dwarf's mass is packed into a super-dense, isothermal core.

Composition: For a typical white dwarf, the core consists of a uniform mixture of carbon and oxygen nuclei swimming in a sea of degenerate electrons. Extremely massive white dwarfs may have oxygen-neon-magnesium cores, while rare low-mass ones have helium cores.

The Electron Sea: The electrons are stripped entirely from their atomic nuclei, forming a high-velocity degenerate gas. This gas acts as an incredible heat conductor, keeping the entire core at a nearly uniform temperature of millions of kelvins.

Crystallization: As the core cools over billions of years, the carbon and oxygen ions stop moving freely. They lock into a rigid, three-dimensional crystalline lattice starting from the center outward, effectively turning the core into a massive metallic diamond.

The Helium Mantle

Wrapping around the massive core is a non-degenerate shell consisting almost entirely of helium. This layer makes up roughly 1% of the star's total mass.

It acts as a transitional chemical boundary where the intense gravity has perfectly separated helium from the heavier carbon and oxygen below.

The Outer Atmosphere

The outermost skin of a white dwarf is incredibly thin, measuring only a few tens of kilometers deep. Yet, it dictates how the star looks to telescopes.

Astronomers categorize white dwarfs into two primary atmospheric types. DA-type white dwarfs have a pure hydrogen surface layer. DB-type white dwarfs have had their hydrogen stripped or mixed away, leaving a pure helium surface.

Gravitational Line up: The surface gravity is roughly 100,000 times stronger than Earth's. This extreme force forces any heavy elements (like iron, calcium, or silicon) to sink out of the atmosphere into the core within days, leaving the pristine, pure hydrogen or helium skin we observe.

Variable white dwarfs (primarily observed as pulsating white dwarfs) are dead stars that undergo periodic changes in brightness. Unlike normal stars, which expand and contract radially, white dwarfs oscillate via non-radial gravity-mode (g-mode) pulsations. In these stars, buoyancy acts as the restoring force, causing the star to squeeze and distort horizontally while keeping its overall volume nearly constant.

These variations are driven by a mechanism known as convective driving or the κ-mechanism. As a cooling white dwarf reaches specific, narrow temperature zones (instability strips), the ionization of elements in its atmosphere traps energy, creating global vibrations that cause its light output to fluctuate by 1% to 30% over periods spanning hundreds to thousands of seconds.

Astronomers categorize variable white dwarfs into distinct classes based on their atmospheric compositions and temperatures.

Variable White Dwarfs

There are the following types of variable white dwarfs with their special properties.

a) DAV Stars (ZZ Ceti Variables)

- **Atmosphere:** Pure hydrogen-dominated (DA spectral type).
- **Temperature Range:** 11,100 K to 12,500 K.
- **Pulsation Period:** 30 seconds to 25 minutes.

These are the most populous class of pulsating white dwarfs. Pulsations are triggered when the temperature drops low enough for hydrogen to become partially ionized, locking in thermal energy and driving the vibrations.

b) DBV Stars (V777 Herculis Variables)

Atmosphere: Helium-dominated, completely lacking hydrogen (DB spectral type).

Temperature Range: 21,000 K to 30,000 K.

Pulsation Period: 100 to 1,100 seconds.

Because helium requires more energy to strip away electrons, these stars undergo convective driving at much higher temperatures than DAV stars.

c) GW Var Stars (DOV & PNNV Variables)

Atmosphere: Helium, carbon, and oxygen rich (PG 1159 spectral type).

Temperature Range: 70,000 K to 140,000 K.

Pulsation Period: 300 to 5,000 seconds.

These are technically ultra-hot "pre-white dwarfs" that are still actively transitioning onto the white dwarf cooling track. Their variations are driven by the ionization of highly stripped carbon and oxygen deep inside their envelopes.

d) DQV Stars and ELMVs

DQV Stars: A newer, rare class of variables with carbon-dominated atmospheres. Their pulsations are likely linked to helium or carbon ionization zones.

ELMVs (Extremely Low-Mass Variables): Discovered in close binary configurations, these are helium-core white dwarfs under 0.3 solar masses. They exhibit high-amplitude, multi-periodic pulsations.

Variable white dwarfs are the premier laboratories for aster seismology—the science of studying star quakes to map stellar interiors. Because different structural layers dampen or amplify specific pulsation frequencies, analyzing their light variations allows scientists to:

1. Measure the exact thickness of the hydrogen and helium shells.
2. Determine the precise core ratio of carbon to oxygen.
3. Trace the exact rate of stellar cooling to act as a cosmic clock for mapping the age of the Milky Way.

Effects of General Relativity

While white dwarfs are often treated using Newtonian gravity, General Relativity (GR) plays a critical role in their structure, stability, and observation. While GR corrections are negligible for low-mass white dwarfs, they become dominant when a star approaches its maximum mass.

The primary manifestations of General Relativity in white dwarf stars include:

The standard Newtonian calculation by Subrahmanyan Chandrasekhar predicts a maximum mass of approximately 1.44 solar masses at which the star's radius shrinks to zero. However, GR alters this calculation. To include GR effects, astronomers must replace Newtonian hydrostatic equilibrium with the TOV equations.

GR treats pressure itself as a source of gravity. Because a white dwarf's core has immense internal pressure, this pressure adds to the inward gravitational pull. As a result, the true relativistic mass limit is actually slightly lower than the Newtonian limit—around 1.38 to 1.41 solar masses depending on core composition (e.g., carbon-oxygen vs. oxygen-neon).

Radical Radius Reduction (Compressibility)

For typical white dwarfs (around 0.6 solar masses), Newtonian and GR predictions for the star's size are nearly identical. But for ultra-massive white dwarfs, GR effects compound rapidly. In Newtonian physics, a white dwarf only becomes unstable when its radius reaches zero (infinite density). GR introduces a radical difference: the onset of dynamic instability occurs at a finite, measurable radius.

When a white dwarf is compressed to a critical central density **10^{10} gm/cc**, the relativistic curvature of spacetime triggers a global instability.

Even if electron degeneracy pressure is theoretically capable of holding up the star, the GR-enhanced gravity overwhelms it, forcing the star to collapse into a neutron star before it can ever reach zero radius.

Direct Observation via Gravitational Redshift

GR provides astronomers with the most precise tool for measuring a white dwarf's mass. Because a white dwarf is compact, light escaping its surface must fight against an intense gravitational well.

Wavelength Shift: This struggle robs the exiting photons of energy, shifting their spectral lines toward redder, longer wavelengths.

Mass-to-Radius Tool: The shift is directly proportional to the ratio of the star's mass to its radius. By cross-referencing this redshift with distance data from missions like the Gaia Space Telescope, scientists can empirically map out the exact white dwarf mass-radius relation.

While white dwarfs are dead stars, they serve as invaluable laboratories for astrophysicists. Because they are compact, stable, and incredibly dense, they act as cosmic clocks, particle accelerators, and elemental deep-freezes.

The primary scientific applications of white dwarf stars include:

Cosmological Distance Indicators (Type Ia Supernovae)

White dwarfs are the engines behind Type Ia supernovae, which act as the universe's **"standard candles".**

The Mechanism: When a white dwarf in a binary system accretes enough mass to cross the Chandrasekhar limit, or when two white dwarfs merge, they undergo a runaway thermonuclear explosion. Because these explosions occur at a precise, predictable mass, they all share an identical intrinsic brightness. By measuring how faint they look from Earth, astronomers mapped the expansion of the universe, leading to the discovery of Dark Energy.

Cosmic Chronometers

White dwarfs do not generate their own heat; they simply cool down over billions of years at a highly predictable rate. By measuring the temperature and brightness of the coolest, oldest white dwarfs in a specific region, astronomers can calculate exactly how long ago those stars formed.

This process, known as white dwarf cosmochronology, is used to determine the precise age of the Milky Way's galactic disk, open stellar clusters, and globular clusters.

Extreme Labs for Fundamental Physics

White dwarfs provide environmental conditions that are entirely impossible to replicate in laboratories on Earth. They are the ultimate testing grounds for Fermi-Dirac statistics and relativistic electron degeneracy pressure.

The cores of cooling white dwarfs transition into a crystalline lattice. Studying this crystallization helps physicists understand high-density plasma physics and condensed matter behaviour under extreme pressure.

Many white dwarfs possess magnetic fields millions of times stronger than Earth's, allowing scientists to study how matter behaves in extreme magnetic environments.

The White Dwarf Habitable Zone

Because white dwarfs release a steady, diminishing stream of residual heat for billions of years, they possess a highly stable habitable zone. Due to the star's low luminosity, this "Goldilocks zone" is incredibly close—roughly 100 times closer than Earth is to the Sun.

Research indicates that if a rocky planet migrates into this close-in zone after the red giant phase, it could theoretically harbour liquid water oceans.

Because white dwarfs are so tiny, a transiting Earth-sized planet blocks nearly all of its light, making their atmospheres the easiest targets for JWST to scan for bio signatures like oxygen or methane.

References

1. B W. Carroll & D A Ostlie, *Introduction to Modern Astrophysics*, CUP.
2. D Koster & G Chanmugam, *Physics of White Dwarfs*, *Physics Reports*.
3. E L Shatzman, *White Dwarfs*, North Holland Publishing Co.

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A Young Scientist's Dream

In 1930, a 19-year-old Indian student named **Subrahmanyan Chandrasekhar** was travelling by ship from India to England to pursue higher studies.

During the long voyage, he carried only a notebook, a pencil, and an insatiable curiosity. As the ship crossed the oceans, he spent hours calculating what happens to stars after they exhaust their nuclear fuel.

His calculations led to a remarkable conclusion: **if a dying star's mass exceeds about 1.4 times the mass of our Sun, it cannot remain a white dwarf.** This critical value became famous as the **Chandrasekhar Limit**.

Many senior scientists initially doubted his work. But Chandrasekhar continued his research with patience and determination. Decades later, his ideas transformed astrophysics, and in 1983 he was awarded the **Nobel Prize in Physics**.

Message:
"Great discoveries often begin with a curious mind, a notebook, and the courage to challenge accepted ideas."

SOME FACTS ABOUT DIAMOND

Diamond is the hardest naturally occurring substance. A large quantity of industrial diamonds are used as drilling bits which are used for drilling hard materials such as concrete. The technical use of diamond is so extensive that, only a small percentage of all diamonds mined are set in jewelry, and the rest proceed towards industrial applications.

It is interesting to note that, they even grow diamonds in the laboratory. After growing, the diamond is cut, polished, and sometimes treated to improve its color and clarity. The final product is chemically and physically the same material as a natural diamond—crystalline carbon.

In today's techniques they can be produced in sizes far larger than what is commonly sold in jewelry stores. However, a lab-grown diamond generally costs substantially less than a natural diamond of same size. A natural diamond may cost 2 to 10 times more than a comparable lab-grown diamond. (In some cases, the difference can be even larger.) For this reason, many consumers choose lab-grown diamonds when they want a larger stone for a given budget.

Now there are 3 categories.

1. Natural diamonds

Formed deep inside the Earth over billions of years.

2. Lab-grown diamonds

Produced in laboratories using processes that replicate the conditions under which diamonds form.

3. Imitation diamonds (simulants)

Materials that only look like diamonds, such as glass, cubic zirconia, or moissanite.

By contrast, glass, stones and cubic zirconia are categorized as "fake" or imitation diamonds because they are intrinsically of different materials (other than carbon).

Now a question arises;

Are lab-grown diamonds categorized as "fake diamonds"?

The answer is,

Lab-grown diamonds are not considered fake diamonds.

A lab-grown diamond has the same crystal structure and is made of the same material i.e., pure carbon arranged in a diamond lattice, as a natural diamond. They also have very high thermal conductivity. Because of this, Gemological laboratories such as, Gemological Institute of America classify them as diamonds, though they must be disclosed as lab-grown.

Modern laboratory techniques have advanced so much that even trained jewellers usually cannot distinguish a lab-grown diamond from a natural diamond by simple inspection methods. Specialized gemological instruments are often required to determine the diamond's origin.

At any cost, the lab-grown diamonds do not fall under the category of Fake Diamonds.

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QUANTUM PHYSICS' STRANGEST PROBLEM MAY HOLD THE KEY TO TIME ITSELF

Scientists have taken a new look at one of quantum physics' strangest problems and found that the answer may reach all the way to time itself.

In quantum mechanics, particles do not behave like everyday objects. Instead of existing in one clearly defined state, they can occupy several possible states at once, a phenomenon known as superposition. Physicists describe this blurry quantum behaviour with a mathematical object called a 'wave function.'

But in the ordinary world, things do not seem to work that way. A chair is in one spot, not two. A clock shows one time, not many. Bridging that gap between the quantum world and daily experience has challenged physicists for decades.

To reconcile this difference, physicists typically argue that when a quantum system interacts with a measuring device or observer, its wave function 'collapses' into a single, definite outcome.

With support from the Foundational Questions Institute (FQxI), an international group of physicists has now investigated a set of unconventional approaches to this measurement problem known as 'quantum collapse models,' revealing that they could have significant consequences for how time behaves and how precisely it can be measured.

Their findings, published in *Physical Review Research*, also propose a new strategy for experimentally distinguishing these models from standard quantum theory.

"What we did was to take seriously the idea that collapse models may be linked to gravity," says Nicola Bortolotti, a PhD student at the Enrico Fermi Museum and Research Centre (CREF) in Rome, Italy, who led the study. "And then we asked a very concrete question: What does this imply for time itself?"

Spontaneous Collapse

During the 1980s, researchers began developing quantum models in which wave function collapse occurs spontaneously, independent of observation or measurement. Unlike standard 'interpretations' of quantum mechanics, which tend to be philosophical frameworks that cannot be distinguished experimentally, these collapse models produce specific predictions that can, in principle, be tested in the lab.

"What we did was to take seriously the idea that collapse models may be linked to gravity. And then we asked a very concrete question: What does this imply for time itself?" says Nicola Bortolotti.

To explore this idea, Bortolotti and colleagues Catalina Curceanu, a member of FQxI and research director at the Laboratori Nazionali di Frascati of the National Institute for Nuclear Physics (INFN-LNF) in Frascati, Italy, Kristian Piscicchia, at CREF and INFN-LNF, Lajos Diósi, of the Wigner Research Center for Physics and Eötvös Loránd University, in Budapest, Hungary, and Simone Manti of INFN-LNF examined two leading collapse models.

One is the Diósi-Penrose model (named after FQxI members Lajos Diósi and Sir Roger Penrose), which has long proposed a connection between gravity and wavefunction collapse. The team also established, for the first time, a quantitative relationship between another model, Continuous Spontaneous Localization, and fluctuations in gravitational spacetime.

The study shows that if these collapse models accurately describe nature, then time itself would carry a minute intrinsic uncertainty. This would introduce a fundamental limit on how precisely time can be measured, although the effect is extraordinarily small.

“Once you do the calculation, the answer is clear and surprisingly reassuring,” said Bortolotti.

Importantly, this predicted uncertainty has no impact on practical timekeeping. Even the most advanced atomic clocks, now or in the foreseeable future, would remain unaffected.

“The uncertainty is many orders of magnitude below anything we can currently measure, so it has no practical consequences for everyday timekeeping,” says Curceanu.

“Our results explicitly show that modern timekeeping technologies are entirely unaffected,” adds Piscicchia.

Linking Quantum Theory and Gravity

For decades, physicists have been searching for a unified framework that can reconcile quantum mechanics with gravity. Each theory is remarkably successful within its own domain.

Quantum mechanics governs the behavior of particles at the smallest scales, while Einstein's general theory of relativity describes gravity and the large-scale structure of the universe. However, the two frameworks treat time in fundamentally different ways.

“In standard quantum mechanics, time is treated as an external, classical parameter that is not affected by the quantum system being studied,” explains Curceanu.

By contrast, in general relativity, time and space are dynamic and can bend and change in response to mass and energy.

“The uncertainty is many orders of magnitude below anything we can currently measure, so it has no practical consequences for everyday timekeeping,” says Catalina Curceanu.

The new results build on the idea that quantum mechanics may be part of a deeper and more comprehensive theory. By revealing a possible link between collapse models, gravity, and the behaviour of time, the work points toward previously hidden connections between these foundational aspects of physics.

Curceanu also emphasized the role of FQxI in supporting unconventional research directions.

“There are not many foundations in the world which are supporting research on these types of fundamental questions about the universe, space, time, and matter,” says Curceanu.

“Our work shows that even radical ideas about quantum mechanics can be tested against precise physical measurements, and that, reassuringly, timekeeping remains one of the most stable pillars of modern physics.”

Reference

“Fundamental limits on clock precision from spacetime uncertainty in quantum collapse models” by Nicola Bortolotti, Catalina Curceanu, Lajos Diósi, Simone Manti and Kristian Piscicchia, **13 November 2025**, *Physical Review Research*.

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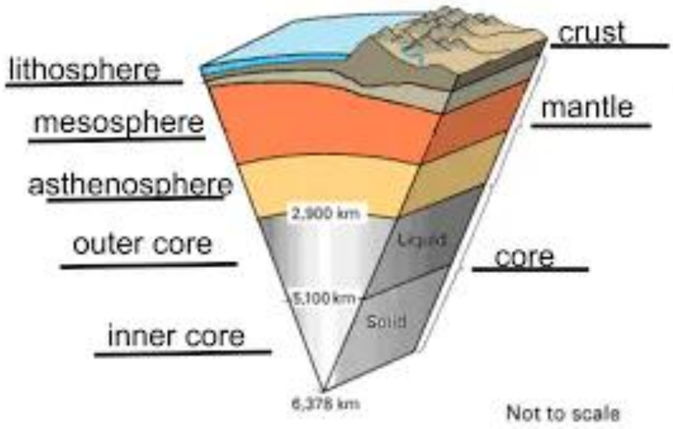
ಸಾಗರಗಳಲ್ಲಿ ಜಾಗತಿಕ ಹವಾಮಾನ ಬದಲಾವಣೆ ಪ್ರಭಾವ

ಜಾಗತಿಕ ತಾಪಮಾನ ಏರಿಕೆಯೆಂದರೆ ಭೂಭಾಗದ ಎಲ್ಲಾ ಕಡೆಯೂ ತಾಪಮಾನ ಏರಿಕೆಯಾಗುತ್ತಿರುವುದು. ಇದು ಭೂಮಿಯ ಸುಮಾರು ೭೦% ಭಾಗವನ್ನು ಆವರಿಸಿರುವ ಸಾಗರಗಳ ಮೇಲೂ ಅಗಾಧವಾದ ಪರಿಣಾಮವನ್ನು ಬೀರುತ್ತಿದೆ. ಭೂವಾತಾವರಣದ ಹಸಿರುಮನೆಯ ಅನಿಲಗಳು ದಿನೇದಿನೇ ಹೆಚ್ಚಾಗುತ್ತಿರುವುದರಿಂದ ಭೂಭಾಗದ ತಾಪಮಾನ ಏರಿಕೆಯ ಜೊತೆಯೇ ಸಮುದ್ರದ ತಾಪಮಾನವೂ ಹೆಚ್ಚಾಗುತ್ತಿದೆ. ಇದು ಸಮುದ್ರದ ಪರಿಸರ ವ್ಯವಸ್ಥೆಯ ಮೇಲೆ ಅಗಾಧವಾದ ದುಷ್ಪರಿಣಾಮ ಬೀರುತ್ತಿದೆ

ಸಾಗರಗಳು ರೂಪುಗೊಂಡ ರೀತಿ:

ಭೂಪದರದ ಮೇಲ್ಮೈಯಾದ ಗಟ್ಟಿ ಹೊರ ಪದರ ಲಿಥೋಸ್ಫಿಯರ್ (ಚಿತ್ರ 1) ಒಂದು ಸಂಪೂರ್ಣ ತುಂಡು ಅಲ್ಲ, ಅದು ದೊಡ್ಡ ಚಿಕ್ಕ ಭಾಗಗಳಾಗಿ ವಿಭಜನೆಯಾಗಿವೆ. ಈ ಭಾಗಗಳನ್ನು ಭೂಫಲಕಗಳು ಅಥವಾ ಟೆಕ್ಟಾನಿಕ್ ಪ್ಲೇಟ್‌ಗಳು ((Tectonic Plates)) ಎನ್ನುತ್ತಾರೆ. ಈ ಭೂಫಲಕಗಳು ಭೂಮಿಯ ಕರಗಿದ ಮ್ಯಾಂಟಲ್ ಮೇಲೆ ನಿಧಾನವಾಗಿ ತೇಲುತ್ತಿವೆ. ಈ ನಿರಂತರ ಚಲನೆಯು ಕೆಲವು ವೇಳೆ ಭೂಕಂಪಗಳು, ಜ್ವಾಲಾಮುಖಿಗಳಿಗೆ ನೇರ ಕಾರಣವಾಗಿದೆ.



ಚಿತ್ರ 1   ಭೂ ಪದರಗಳು

ಸುಮಾರು 200 ದಶಲಕ್ಷ ವರ್ಷಗಳ ಹಿಂದೆ ಭೂಮಿಯಲ್ಲಿ ಒಂದು ಬೃಹತ್ ಭೂಖಂಡ ಅಸ್ತಿತ್ವದಲ್ಲಿತ್ತು. ಭೂಮಿಯ ಮೇಲಿನ ಎಲ್ಲಾ ಖಂಡಗಳು ಸೇರಿಕೊಂಡಿದ್ದ ಈ ಸ್ಥಿತಿಯನ್ನು ಪಾಂಗೇಯ ((Pangea),), ಅಂದರೆ ಗ್ರೀಕ್‌ನಲ್ಲಿ 'ಆಲ್ ಅರ್ಥ್' ಎಂದು ಅರ್ಥ. ಮೊದಲು ಪಾಂಗೇಯ ಉತ್ತರದಲ್ಲಿ 'ಲಾರೇಶಿಯಾ' ಮತ್ತು ದಕ್ಷಿಣದಲ್ಲಿ 'ಗೊಂಡ್ವಾನ' ಎಂಬ ದೊಡ್ಡ ಭೂಭಾಗಗಳಾಗಿ ಒಡೆಯಿತು. ಇವುಗಳು ಬೇರ್ಪಟ್ಟಾಗ ನಡುವಿನಲ್ಲಿ **ನೀರು ತುಂಬಿ ಅಟ್ಲಾಂಟಿಕ್ ಮತ್ತು ಹಿಂದೂ ಮಹಾಸಾಗರಗಳಾಗಿ ರೂಪುಗೊಂಡವು.** ಲಕ್ಷಾಂತರ ವರ್ಷಗಳನಂತರ ಗೊಂಡ್ವಾನ ಮತ್ತು ಲಾರೇಶಿಯಾ ಒಡೆದು ಚೂರಾಗಿ ಇಂದು ನಮಗೆ ತಿಳಿದಿರುವಂತೆ ವಿಭಜನೆಯಾಗಿ ದಕ್ಷಿಣ ಅಮೆರಿಕ, ಆಫ್ರಿಕಾ, ಉತ್ತರ ಅಮೆರಿಕಾ, ಯೂರೋಪ್, ಏಷ್ಯಾ, ಆಸ್ಟ್ರೇಲಿಯಾ ಮತ್ತು ಅಂಟಾರ್ಟಿಕಾ ಖಂಡಗಳಾಗಿ ಚಲಿಸಿವೆ. ಈ ಪ್ರಕ್ರಿಯೆಗೆ 'ಕಾಂಟಿನೆಂಟಲ್ ಡ್ರಿಫ್ಟ್' ಎನ್ನುತ್ತಾರೆ. ಈ ಖಂಡಗಳು ಇಂದಿಗೂ ವರ್ಷಕ್ಕೆ ಕೆಲವು ಸೆಂಟಿಮೀಟರ್‌ನಷ್ಟು ನಿಧಾನವಾಗಿ ಚಲಿಸುತ್ತಲೇ ಇವೆ.

ಭೂಮಿಯ ಮಹಾಸಾಗರಗಳು ಸುಮಾರು ನಾಲ್ಕು ಶತಕೋಟಿ ವರ್ಷಗಳ ಹಿಂದೆ ಸುದೀರ್ಘ ಪ್ರಕ್ರಿಯೆಗಳ ಮೂಲಕ ರೂಪುಗೊಂಡವು. ಕೆಲವು ವಿಜ್ಞಾನಿಗಳ ಪ್ರಕಾರ 'ಭೂಮಿಗೆ ಅಪ್ಪಳಿಸಿದ ಮಂಜುಗಡ್ಡೆಯಿಂದ ತುಂಬಿದ ಧೂಮಕೇತುಗಳು ಭೂಮಿಗೆ ಹೆಚ್ಚಿನ ಪ್ರಮಾಣದಲ್ಲಿ ನೀರನ್ನು ತಂದಿರಬಹುದು ಎನ್ನುತ್ತಾರೆ' . ಮತ್ತೊಂದು ಸಿದ್ಧಾಂತದ ಪ್ರಕಾರ 'ಭೂಮಿಯು ತಣ್ಣಗಾದಂತೆ ವಾತಾವರಣದ ಮಳೆ ಗಾಳಿಯು ಸಾಂದ್ರೀಕರಣಗೊAಡು

ಶತಮಾನಗಳವರೆಗೆ ಮಳೆಯು ಸುರಿದು, ಭೂಮಿಯ ಮೇಲ್ಮೈಯ 70% ಭಾಗದಲ್ಲಿ ಶೇಖರಣೆಯಾಗಿ ಮಹಾಸಾಗರಗಳು ರೂಪಗೊಂಡವು' . ಈಗ ನೋಡುವಂತೆ ಭೂಮಿಯ ಐದು ಮಹಾಸಾಗರಗಳು ಕೆಳಗಿನಂತಿವೆ.

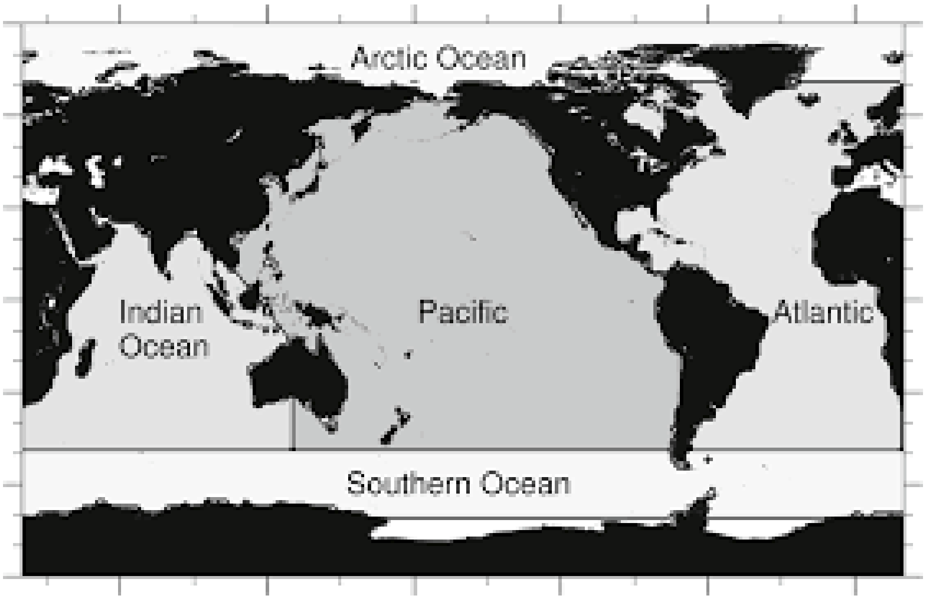
ಫೆಸಿಫಿಕ್ ಮಹಾಸಾಗರವು ಭೂಮಿಯ ಅತ್ಯಂತ ದೊಡ್ಡ ಮತ್ತು ಆಳವಾದ ಸಾಗರ. ಇದಕ್ಕೆ ಶಾಂತ ಸಾಗರ ಎಂಬ ಹೆಸರನ್ನಿಟ್ಟವರು ಪೋರ್ಚುಗೀಸ್ ನಾವಿಕ ಫೆರ್ಡಿನೆಂಡ್ ಮೆಗಲಿನ್. ಫೆಸಿಫಿಕ್ ಎಂದರೆ ಲ್ಯಾಟಿನ್‌ನಲ್ಲಿ ಶಾಂತವಾದ ಎಂದು. ಏಷ್ಯಾ ಮತ್ತು ಆಸ್ಟ್ರೇಲಿಯಾ ಪೂರ್ವದ ಪ್ರದೇಶಗಳನ್ನು ಹೊಂದಿರುವ ಫೆಸಿಫಿಕ್ ಮಹಾಸಾಗರವು ಭೂಮಿಯ ವಿಸ್ತೀರ್ಣದ ಸುಮಾರು 35.25% ಪ್ರದೇಶವನ್ನು ಆವರಿಸಿದೆ. ಈ ಸಾಗರದಲ್ಲಿ ಅತ್ಯಂತ ಹೆಚ್ಚು ದ್ವೀಪ ಸಮೂಹಗಳಿವೆ.

ಅಟ್ಲಾಂಟಿಕ್ ಮಹಾಸಾಗರ ಭೂಮಿಯ ಮಹಾ ಸಾಗರಗಳಲ್ಲಿ ಎರಡನೇ ದೊಡ್ಡ ಸಾಗರವಾಗಿದ್ದು, ಭೂಮಿಯ 20% ಭಾಗವನ್ನು ಆಕ್ರಮಿಸಿದೆ. ಆಫ್ರಿಕಾ, ಯೂರೋಪ್ ಮತ್ತು ಅಮೆರಿಕಾ ಭೂಖಂಡಗಳ ನಡುವೆ ವ್ಯಾಪಿಸಿರುವ ಇದು, ಎಲ್ಲಾ ಸಾಗರಗಳ ಪೈಕಿ ಅತಿ ಪ್ರಕ್ಷುಬ್ಧವಾಗಿದೆ.

ಹಿಂದೂ ಮಹಾಸಾಗರವು ಭೂಮಿಯ ಮೂರನೇ ದೊಡ್ಡ ಸಾಗರ. ಇದು ದಕ್ಷಿಣ ಧ್ರುವದ ಅಂಟಾರ್ಟಿಕ ಸಾಗರ ಪ್ರದೇಶದಿಂದ ಕನ್ಯಾಕುಮಾರಿಯವರೆಗೆ ಹರಡಿಕೊಂಡಿದೆ. ಒಟ್ಟು ಭೂಮಿಯ 14.6% ಪ್ರದೇಶವನ್ನು ಆಕ್ರಮಿಸಿರುವ ಇದು ಅತಿ ಹೆಚ್ಚಿನ 7725 ಮೀ. ಆಳವನ್ನು ಹೊಂದಿದೆ. ಪೂರ್ವಕ್ಕೆ ಚೀನಾ, ಆಸ್ಟ್ರೇಲಿಯಾ ಪಶ್ಚಿಮಕ್ಕೆ ಅರೇಬಿಯನ್ ಪೆನಿಸುಲಾ, ಭಾರತ ಮತ್ತು ದಕ್ಷಿಣಕ್ಕೆ ಅಂಟಾರ್ಟಿಕ ಸಾಗರದಿಂದ ಸುತ್ತುವರೆದಿದೆ. ಈ ಸಾಗರದ ಒಳಗಿರುವ ಮುಖ್ಯ ದ್ವೀಪರಾಷ್ಟ್ರಗಳು ಮಡಗಾಸ್ಕರ್, ರಿಯೂನಿಯನ್ ದ್ವೀಪ, ಕೊಮೊರೋಸ್, ಮಾಲ್ಡೀವ್ಸ್, ಮಾರಿಷಸ್ ಮತ್ತು ಶ್ರೀಲಂಕಾ.

ದಕ್ಷಿಣ ಸಾಗರವನ್ನು ಅಂಟಾರ್ಟಿಕ ಸಾಗರವೆಂದೂ ಕರೆಯುವರು. ಇದು ಸರಾಸರಿ 3701 ಮೀ. ಆಳವಿದ್ದು ನಾಲ್ಕನೇ ದೊಡ್ಡ ಸಾಗರವಾಗಿದೆ. ಇದು ಅಂಟಾರ್ಟಿಕ ಖಂಡವನ್ನು ಸುತ್ತುವರೆದಿದೆ.

ಆರ್ಕ್ಟಿಕ್ ಸಮುದ್ರವು ಭೂಮಿಯ ಅತ್ಯಂತ ಚಿಕ್ಕ ಸಮುದ್ರವಾಗಿದ್ದು, ಭೂಮಿಯ ಉತ್ತರಧ್ರುವವನ್ನು ಸುತ್ತಲೂ ಆವರಿಸಿಕೊಂಡಿದೆ, ಅತ್ಯಂತ ಶೀತವಾಯುಗುಣವಿರುವ ಪ್ರದೇಶ. ಇದು ಗ್ರೀನ್‌ಲ್ಯಾಂಡ್, ನಾರ್ವೆ ಮುಂತಾದ ದೇಶಗಳನ್ನು ಒಳಗೊಂಡಿದೆ. ಸಮುದ್ರದ 182 ಮೀ. ಆಳದವರೆಗೂ ನೀರು ಘನೀಭವಿಸಲು ಬೇಕಾಗುವ ಉಷ್ಣತೆಗಿಂತಲೂ ಕಡಿಮೆ ಇರುತ್ತದೆ.



ಚಿತ್ರ 2 ಭೂಮಿಯ ಸಾಗರಗಳು

ಭೂಮಿಯ ಪ್ಲೇಟ್ ಟೆಕ್ಟಾನಿಕ್ಸ್ ಮತ್ತು ಶಿಲಾ ಚಕ್ರಗಳು:

ಪ್ಲೇಟ್ ಟೆಕ್ಟಾನಿಕ್ಸ್ ಅಥವಾ ಭೂಫಲಕ: ಭೂಮಿಯ ವಾತಾವರಣದಲ್ಲಿನ ಇಂಗಾಲದ ಡೈಆಕ್ಸೈಡ್ ಕೋಟ್ಯಂತರ ವರ್ಷಗಳಿಂದಲೂ ಹೇಗೆ ನಿಯಂತ್ರಣವಾಗುತ್ತಿದೆ ಎಂಬುದನ್ನು ತಿಳಿಯಲು ಪ್ಲೇಟ್ ಟೆಕ್ಟಾನಿಕ್ಸ್ ಮತ್ತು ಶಿಲಾ ಚಕ್ರ ಬಹಳ ಮುಖ್ಯ. ಭೂಮಿಯ ಹೊರಪದರವು (crust) ಅನೇಕ ಟೆಕ್ಟಾನಿಕ್ಸ್ ಫಲಕಗಳಿಂದ ಕೂಡಿದ್ದು ಚಲಿಸುತ್ತಿರುತ್ತವೆ. ಕೆಲವೊಮ್ಮೆ ಅವು ಒಂದಕ್ಕೊಂದು ದೂರವಾಗುತ್ತವೆ, ಒಂದಕ್ಕೊAದು ಡಿಕ್ಕಿ ಹೊಡೆಯುತ್ತವೆ, ಮತ್ತೆ ಕೆಲವೊಮ್ಮೆ

ಒಂದರ ಕೆಳಗೆ ಒಂದು ಇಳಿಯುತ್ತವೆ. ಈ ಚಲನೆಗಳು ಇಂಗಾಲದ ಡೈಆಕ್ಸೆöÉಡ್‌ಅನ್ನು ಭೂಮಿಯ ಒಳಗೆ ಮತ್ತು ಹೊರಗೆ ಸಾಗಿಸುವ ಎಂಜಿನ್ ಆಗಿವೆ.

ಶಿಲಾ ಚಕ್ರ: ಭೂಮಿಯಲ್ಲಿರುವ ಖನಿಜ, ಶಿಲೆ ಮುಂತಾದವುಗಳು ನಿರಂತರವಾಗಿ ರೂಪಾಂತರ ಹೊಂದುತ್ತಾ ಇರುತ್ತವೆ. ಶಿಲೆಗಳು ಒಂದು ರೀತಿಯಿಂದ ಮತ್ತೊಂದು ರೀತಿಗೆ ಬದಲಾಗುವ ಪ್ರಕ್ರಿಯೆಯನ್ನು ಶಿಲಾ ಚಕ್ರವೆನ್ನುವರು. ಅದರಲ್ಲಿ ಶಿಲಾ ಚಕ್ರ ಮತ್ತು ಇಂಗಾಲದ ಚಕ್ರ ಪರಸ್ಪರ ಸಂಬಂಧಪಟ್ಟಿವೆ. ಶಿಲೆಗಳ ಮೂರು ಪ್ರಾಕಾರಗಳು 1. ಅಗ್ನಿಜ ಶಿಲೆಗಳು (Igneous Rocks) ಅಗ್ನಿ ಪರ್ವತಗಳ ಲಾವಾ ತಣ್ಣಗಾದಾಗ ರೂಪುಗೊಳ್ಳುತ್ತವೆ. ಉದಾಹರಣೆಗೆ ಗ್ರಾನೈಟ್, ಬಸಾಲ್ಟ್. 2. ಅವಕ್ಷೇಪ ಶಿಲೆಗಳು (sedimentary rocks). ಉದಾಹರಣೆಗೆ ಲೈಮ್‌ಸ್ಟೋನ್. 3. ಪರಿವರ್ತಿತ ಶಿಲೆಗಳು ಹೆಚ್ಚು ಒತ್ತಡ ಮತ್ತು ಉಷ್ಣದಿಂದ ಬದಲಾಗುತ್ತವೆ. ಉದಾಹರಣೆಗೆ ಮಾರ್ಬಲ್. ಈ ಪ್ರಕ್ರಿಯೆಯಲ್ಲಿ ಇಂಗಾಲ ಸಂಗ್ರಹ, ಬಿಡುಗಡೆ, ಮತ್ತು ಮರುಸಂಚಾರ ನಡೆಯುತ್ತದೆ.

ರಾಸಾಯನಿಕ ವಾತಾವರಣದ ಪ್ರಕ್ರಿಯೆ: ವಾತಾವರಣದಲ್ಲಿನ ಕೆಲವು ಭಾಗ ಇಂಗಾಲದ ಡೈಆಕ್ಸೈಡ್ ಮಳೆಯ ನೀರಿನಲ್ಲಿ ಕರಗಿ ಕಾರ್ಬಾನಿಕ್ ಆಮ್ಲವಾಗಿ ವಾತಾವರಣದಿಂದ ತೆಗೆದುಹಾಕಲ್ಪಟ್ಟು ನಂತರ ಇವು ನಿಧಾನವಾಗಿ ಭೂಮಿಯ ಸಿಲಿಕೇಟ್ ಶಿಲೆಗಳೊಡನೆ ಪ್ರಕ್ರಿಯೆ ನಡೆಸಿ, ಜೇಡಿ ಮಣ್ಣು (ಕ್ಲೆ ಮಣ್ಣು), ಕರಗಿದ ಸಿಲಿಕಾ ಮತ್ತು ಬೈಕಾರ್ಬೋನೇಟ್‌ಗಳನ್ನು ಉತ್ಪಾದಿಸುತ್ತದೆ. ಈ ಪ್ರಕ್ರಿಯೆಯನ್ನು ಸಿಲಿಕೇಟ್ ವಾತಾವರಣೀಕರಣ ಎಂದು ಕರೆಯುತ್ತಾರೆ.

ಸಮುದ್ರದ ಆಮ್ಲೀಯತೆ:

ವಾತಾವರಣ ಬದಲಾವಣೆ ಮತ್ತು ಸಮುದ್ರದ ಆಮ್ಲೀಯತೆ ಒಂದೇ ಸಮಸ್ಯೆಯ ಎರಡು ಮುಖಗಳಿದ್ದಂತೆ. ಕೈಗಾರಿಕೆ, ವಾಹನಗಳ ಚಾಲನೆಯಿಂದ ಬಿಡುಗಡೆಯಾಗುವ ಇಂಗಾಲದ ಡೈಆಕ್ಸೈಡ್, ಅರಣ್ಯ ನಾಶ, ಪಳೆಯುಳಿಕೆ ಉತ್ಪಾದನೆಗಳಾದ ಪೆಟ್ರೋಲ್, ಡೀಸೆಲ್‌ಗಳ ದಹನ ಮುಂತಾದವುಗಳಿಂದ ವಾತಾವರಣಕ್ಕೆ ಹೆಚ್ಚು ಪ್ರಮಾಣದಲ್ಲಿ ಇಂಗಾಲದ ಡೈಆಕ್ಸೈಡ್ ಬಿಡುಗಡೆಯಾಗುತ್ತಿದೆ. ಇದರಲ್ಲಿ 25% ನಿಂದ 30% ಇಂಗಾಲದ ಡೈಆಕ್ಸೈಡ್ ಸಾಗರಗಳ ನೀರಿನಲ್ಲಿ ಕರಗಿ ಕಾರ್ಬಾನಿಕ್ ಆಸಿಡ್ ಆಗಿ ಅದನ್ನು ಆಮ್ಲೀಯಗೊಳಿಸುತ್ತಿದೆ. ಹೀಗೆ ವಾತಾವರಣದಲ್ಲಿನ ಇಂಗಾಲಾಮ್ಲವು ಸಮುದ್ರದ ನೀರಿನಲ್ಲಿ ಕರಗಿ ಕಾರ್ಬಾನಿಕ್ ಆಮ್ಲವನ್ನುಂಟುಮಾಡುತ್ತದೆ. ಈ ಕಾರ್ಬಾನಿಕ್ ಆಮ್ಲವು ವಿಭಜನೆಗೊಂಡು ಜಲಜನಕದ ಅಯಾನ್(H+) ಗಳನ್ನು ಬಿಡುಗಡೆ ಮಾಡುತ್ತದೆ. ಈ ಜಲಜನಕದ ಅಯಾನ್ ಪ್ರಮಾಣವು ಹೆಚ್ಚಾದಂತೆ ಪಿಎಚ್ (PH) ಪ್ರಮಾಣವು ಕಡಿಮೆಯಾಗಿ ಸಮುದ್ರವು ಹೆಚ್ಚು ಆಮ್ಲೀಯವಾಗಲು ಕಾರಣವಾಗುತ್ತದೆ. ಕೈಗಾರಿಕಾ ಕ್ರಾಂತಿಯ ನಂತರ ಸಮುದ್ರದ PH ಸುಮಾರು 0.1 ಅಳತೆಯಷ್ಟು ಕಡಿಮೆಯಾಗಿದೆ. ಇದು 25.30% ಆಮ್ಲೀಯ ಹೆಚ್ಚಳಕ್ಕೆ ಸಮಾನವಾಗಿದೆ.

ಸಮುದ್ರದ ಆಮ್ಲೀಕರಣವನ್ನು ಅನೇಕ ಸಂಸ್ಥೆಗಳು ವೈಜ್ಞಾನಿಕವಾಗಿ ಅಧ್ಯಯನ ಮಾಡಿ ದೃಢಪಡಿಸಿವೆ. ಐಪಿಸಿಸಿ (Intergovernmental panel on Climate Change) ಸಂಸ್ಥೆಯು ಸಮುದ್ರಗಳಲ್ಲಿ ಹವಾಮಾನ ಬದಲಾವಣೆಯನ್ನು ಕುರಿತು ಮಹತ್ವದ ಅಧ್ಯಯನ ಮಾಡುತ್ತಿದೆ. ವಿಶ್ವದ ಅನೇಕ ವಿಜ್ಞಾನಿಗಳ ಸಂಶೋಧನೆಯ ವಿಶ್ಲೇಷಣೆಯ ಪ್ರಕಾರ 1. ಜಾಗತಿಕ ತಾಪಮಾನ ಏರಿಕೆಯಿಂದ ಸಮುದ್ರಗಳು ಹೆಚ್ಚು ಉಷ್ಣತೆಯನ್ನು ಹೀರಿಕೊಳ್ಳುತ್ತಿವೆ. ಭೂಮಿಯ ಹಸಿರುಮನೆಯಲ್ಲಿ ಸೇರುವ ಹೆಚ್ಚುವರಿ ಉಷ್ಣತೆಯ 90% ಗಿಂತಲೂ ಹೆಚ್ಚು ಸಮುದ್ರವನ್ನು ಸೇರುತ್ತಿದೆ. ಇದರಿಂದ ಸಮುದ್ರ ಜೀವಿಗಳಿಗೆ ತೊಂದರೆಯುAಟಾಗಿದೆ. 2. ಸಮುದ್ರದ ನೀರು ಹೆಚ್ಚು ಆಮ್ಲೀಕರಣವಾಗುತ್ತಿರುವುದರಿಂದ ಶಂಖ, ಮುತ್ತು, ಹವಳಗಳನ್ನು ಉತ್ಪತ್ತಿಮಾಡುವ ಜೀವಿಗಳಿಗೆ ಹಾನಿಯಾಗಿ ಅವುಗಳು ಅಳಿವಿನಂಚಿಗೆ ಬರುತ್ತಿವೆ. 3. ಹಿಮನದಿಗಳು ಕರಗುತ್ತಿರುವುದರಿಂದ ಸಮುದ್ರಮಟ್ಟ ಏರಿಕೆಯಾಗಿ ಕರಾವಳಿ ಪ್ರದೇಶಗಳು ಅಪಾಯ ಎದುರಿಸುತ್ತಿವೆ. 4. ಸಮುದ್ರದ ಜೀವ ವೈವಿಧ್ಯತೆಗೆ ಹೆಚ್ಚಿನ ದುಷ್ಪರಿಣಾಮ ಬೀರುತ್ತದೆ. 5. ಸಮುದ್ರ ಪ್ರವಾಹಗಳು ದಿಕ್ಕನ್ನು ಬದಲಾಯಿಸುತ್ತಿವೆ ಉದಾಹರಣೆಗೆ, ಅಟ್ಲಾಂಟಿಕ್ ಮೆರಿಡಿಯನ್‌ನಲ್ಲಿ ಅತಿ ಹೆಚ್ಚು ಪ್ರವಾಹಗಳು ಉಂಟಾಗಿವೆ. 5. ತೀವ್ರ ಹವಾಮಾನ ಘಟನೆಗಳಾದ ಚಂಡಮಾರುತಗಳು ಹೆಚ್ಚು ಬಲವಾಗುತ್ತಿವೆ. ಸಮುದ್ರ ಉಷ್ಣ ಅಲೆಗಳು ಮತ್ತು ಕರಾವಳಿ ಪ್ರವಾಹಗಳು ಹೆಚ್ಚಾಗುತ್ತಿವೆ.

ಸಮುದ್ರದಲ್ಲಿ ಇಂಗಾಲ ಸಂಗ್ರಹ:

ನದಿಗಳ ಮೂಲಕ ಕರಗಿದ ಖನಿಜಗಳಾದ ಕ್ಯಾಲ್ಸಿಯಂ, ಮೆಗ್ನೀಸಿಯಂ ಮುಂತಾದವು ಸಮುದ್ರದಲ್ಲಿ ಸಂಗ್ರಹವಾದಾಗ, ಸಮುದ್ರ ಜೀವಿಗಳು ಈ ಖನಿಜಗಳಿಂದ ಕೋರಲ್ಸ್, ಶೆಲ್‌ಗಳನ್ನು ನಿರ್ಮಿಸಿಕೊಳ್ಳುತ್ತವೆ.

ಸಾಗರ ಆಮ್ಲೀಯತೆಯಿಂದ ಪ್ರಮುಖ ಪರಿಣಾಮಗಳು:

ಸಾಗರ ಆಮ್ಲೀಯತೆಯು ಹವಳ ನಿರ್ಮಿಸುವ ಪಾಲಿಪ್ಸ್ (Polyps) ಮತ್ತು ಮೃದ್ವಂಗಿ (Mollusks) ಪ್ರಾಣಿಗಳಿಗೆ ತಮ್ಮ ಚಿಪ್ಪುಗಳು ಮತ್ತು ಅಸ್ಥಿಪಂಜರಗಳನ್ನು ನಿರ್ಮಿಸಲು ಅಗತ್ಯವಿರುವ ಕಾರ್ಬೋನೇಟ್ ಅಯಾನುಗಳನ್ನು ಇದು

ಕಡಿಮೆ ಮಾಡುತ್ತದೆ. ಕ್ಯಾಲ್ಸಿಯಂ ಕಾರ್ಬೋನೇಟ್‌ನ ರೂಪವಾದ ಅರಗೊನೈಟ್‌ಅನ್ನು ಸಮುದ್ರಜೀವಿಗಳು ತಮ್ಮ ಅಸ್ಥಿಪಂಜರ ಮತ್ತು ಚಿಪ್ಪುಗಳನ್ನು ನಿರ್ಮಿಸಲು ಬಳಸುತ್ತವೆ. ಸಾಗರ ಆಮ್ಲೀಯತೆಯಿಂದ ಇದರ ಶುದ್ದತ್ವ ಕಡಿಮೆಯಾಗಿ ಚಿಪ್ಪುಗಳನ್ನು ನಿರ್ಮಿಸುವುದು ಅವುಗಳಿಗೆ ಕಷ್ಟಕರವಾಗುತ್ತದೆ.

ಸಮುದ್ರ ಜೀವಿಗಳ ಬೆಳವಣಿಗೆಯು ಕುಂಠಿತವಾಗುವುದರಿಂದ ಸಮುದ್ರ ಪರಿಸರ ವ್ಯವಸ್ಥೆ ಮತ್ತು ಮೀನುಗಾರಿಕೆಯ ಮೇಲೆ ವ್ಯತಿರಿಕ್ತ ಪರಿಣಾಮವನ್ನು ಬೀರುತ್ತದೆ. ಇದರಿಂದ ಅನೇಕ ಜನರ ಆಹಾರ ಮತ್ತು ಜೀವನೋಪಾಯಕ್ಕೆ ನೇರವಾಗಿ ಪರಿಣಾಮ ಬೀರುತ್ತದೆ. ಜಾಗತಿಕವಾಗಿ ಸುಮಾರು ಒಂದು ಶತಕೋಟಿ ಜನರು ಹವಳದ ದಿಬ್ಬಗಳು, ಮೀನುಗಾರಿಕೆ, ಪ್ರವಾಸೋದ್ಯಮ ಮತ್ತು ಕರಾವಳಿ ನಿರ್ವಹಣಾ ಸೇವೆಗಳ ಮೇಲೆ ಅವಲಂಬಿತವಾಗಿರುವುದರಿAದ ಸಾಗರಗಳ ನಿರಂತರ ಆಮ್ಲೀಕರಣವು ಭವಿಷ್ಯದ ಆಹಾರ ಸರಪಳಿಗೆ ಅಪಾಯವನ್ನುಂಟುಮಾಡುತ್ತದೆ.

ಹವಾಮಾನ ಬದಲಾವಣೆಯಿಂದ ಕ್ರಯೋಸ್ಫಿಯರ್ (ಹಿಮಮಂಡಲ) ಮೇಲೆ ಪರಿಣಾಮ:

ಕ್ರಯೋಸ್ಫಿಯರ್ ಎಂದರೆ ಭೂಮಿಯಲ್ಲಿರುವ ಎಲ್ಲಾ ಹಿಮ ಸಂಬಂಧಿತವಾದ ಭಾಗಗಳಾದ ನದಿಗಳು, ಧ್ರುವ ಪ್ರದೇಶಗಳು, ಗ್ಲೇಸಿಯರ್‌ಗಳು, ಸಮುದ್ರ ಹಿಮ, ಹಿಮಾವೃತ ಮಣ್ಣು, ಹಿಮಪಾತ ಪ್ರದೇಶಗಳನ್ನೊಳಗೊಂಡಿದೆ.

1. ಹಿಮನದಿಗಳ ಕರಗುವಿಕೆ: ಜಾಗತಿಕ ತಾಪಮಾನ ಏರಿಕೆಯಿಂದ ಹಿಮನದಿಗಳು ವೇಗವಾಗಿ ಕರಗುತ್ತಿವೆ. ಧ್ರುವ ಪ್ರದೇಶಗಳ ಹಿಮಗಳು ಮತ್ತು ಉಳಿದೆಲ್ಲೆಡೆ ಸಹಿತ ಹಿಮಾಲಯಾ ಪ್ರದೇಶದಲ್ಲಿಯೂ ಹಿಮನದಿಗಳು ಕಡಿಮೆಯಾಗುತ್ತಿವೆ. ನದಿಗಳ ನೀರಿನ ಹರಿವು ಬದಲಾಗುತ್ತಿವೆ. ಇದರಿಂದ ಕುಡಿಯುವ ನೀರಿನ ಕೊರತೆ, ಕೃಷಿಗೆ ಹಾನಿಯಾಗುವ ಪರಿಸ್ಥಿತಿಯುಂಟಾಗುವ ಸಂಭವ ಹೆಚ್ಚು.

2. ಧ್ರುವ ಪ್ರದೇಶಗಳಾದ ಗ್ರೀನ್‌ಲ್ಯಾಂಡ್, ಅಂಟಾರ್ಟಿಕಗಳಲ್ಲಿ ಮಂಜುಗಡ್ಡೆ ವೇಗವಾಗಿ ಕರಗುತ್ತಿದೆ. ಇದರಿಂದ ಸಮುದ್ರಮಟ್ಟವು ಹೆಚ್ಚಿ ಕರಾವಳಿ ಪ್ರದೇಶದ ನಗರಗಳು ಅಪಾಯವನ್ನೆದುರಿಸಬೇಕಾಗುತ್ತದೆ.

3. ಜಾಗತಿಕ ತಾಪಮಾನ ಹೆಚ್ಚಳದಿಂದಾಗಿ ಧ್ರುವ ಪ್ರದೇಶದಲ್ಲಿ ಹಿಮದ ವಿಸ್ತೀರ್ಣ ಕಡಿಮೆಯಾಗುತ್ತಿದೆ. ಬೇಸಿಗೆಯಲ್ಲಿ ಹಿಮ ಸಂಪೂರ್ಣ ಕರಗುವ ಸಾಧ್ಯತೆ ಇದೆ. ಇದರ ಪರಿಣಾಮವಾಗಿ ಜಾಗತಿಕ ಹವಾಮಾನ ಮಾದರಿಗಳು ಬದಲಾಗುತ್ತಿವೆ, ಧ್ರುವ ಕರಡಿಗಳು ವಾಸಸ್ಥಳ ಕಳೆದುಕೊಳ್ಳುವ ಅಪಾಯವಿದೆ. ಅಲ್ಲದೆ ಸಮುದ್ರದ ನೀರಿನ ಮಟ್ಟ ತೀವ್ರವಾದ ಏರಿಕೆಗೆ ಕಾರಣವಾಗಿದೆ.

4.

5. **ಚಿತ್ರ 3 ಕ್ರಯೋಸ್ಫಿಯರ್**

6. ಸದಾ ಹಿಮದಲ್ಲಿರುವ ಮಣ್ಣು ಈಗ ಹಿಮ ಕರಗಿ ಹೊರಬರುತ್ತಿದೆ. ಇದರೊಳಗೆ ಸಂಗ್ರಹವಾಗಿರುವ ಇಂಗಾಲಾಮ್ಲ ಮತ್ತು ಮೀಥೇನ್ ಹೊರಬರುವುದರಿಂದ ಅವು ವಾತಾವರಣ ಸೇರಿ ಹಸಿರುಮನೆ ಪರಿಣಾಮ ಹೆಚ್ಚುತ್ತದೆ. ಇದರಿಂದ ಜಾಗತಿಕ ತಾಪಮಾನ ಮತ್ತಷ್ಟು ವೇಗವಾಗುತ್ತದೆ.

7. ಹಿಮ-ಅಲ್ಬಿಡೋ ಪರಿಣಾಮ (Ice-Albedo effect) ದಿಂದ, ಹಿಮವು ಸೂರ್ಯನ ಕಿರಣಗಳನ್ನು ಪ್ರತಿಫಲಿಸುವಂತೆ ಮಾಡಿ ಸೂರ್ಯನ 80-90% ಶಾಖ ಮತ್ತು ಬಿಸಿಲನ್ನು ಬಾಹ್ಯಾಕಾಶಕ್ಕೆ ಪ್ರತಿಫಲಿಸುವಂತೆ ಮಾಡುತ್ತದೆ. ಹೀಗಾಗಿ ಭೂಮಿಯು ತಂಪಾಗಿ ಉಳಿಯುತ್ತದೆ. ಆದರೆ ಹಿಮದ ಸುತ್ತಮುತ್ತಲ ನೀರು ಸೂರ್ಯನ ಶಾಖವನ್ನು ಹೀರಿಕೊಳ್ಳುವುದರಿಂದ ನೀರು ಶಾಖಗೊಂಡು ಸುತ್ತಮುತ್ತಲ ಪರಿಸರವನ್ನು ಬಿಸಿಮಾಡಿ ಹಿಮ ಕರಗುವಂತೆ ಮಾಡಬಹುದು.

8. ಸಮುದ್ರದ ನೀರು ಬಿಸಿಯಾದಾಗ ಅದು ವಿಸ್ತರಿಸುತ್ತದೆ. ಆಗ ಅದು ಹೆಚ್ಚಿನ ಜಾಗವನ್ನು ಆಕ್ರಮಿಸುವುದರಿಂದ ಸಮುದ್ರದ ನೀರಿನ ಮಟ್ಟವು ತೀವ್ರವಾಗಿ ಏರಲು ಮತ್ತೊಂದು ಕಾರಣವಾಗಿದೆ.

9. ಸಮುದ್ರದ ಮೇಲ್ಮೆಯ ತಾಪಮಾನವು ಅತಿಯಾಗಿ ಹೆಚ್ಚುತ್ತಿದ್ದು ಸಮುದ್ರ ಉಷ್ಣ ಅಲೆಗಳಿಗೆ ಕಾರಣವಾಗುತ್ತಿದೆ.

10. ಸಮುದ್ರಗಳು ಹೆಚ್ಚಿನ ಇಂಗಾಲದ ಡೈಆಕ್ಸೆöÊಡ್‌ಅನ್ನು ಹೀರಿಕೊಳ್ಳುವುದರಿಂದ ನೀರಿನ ಆಮ್ಲೀಯತೆ ಹೆಚ್ಚಾಗಿ ಆಮ್ಲಜನಕದ ಮಟ್ಟ ಇಳಿಕೆಯಾಗುತ್ತಿದೆ. ಇದರಿಂದಾಗಿ ಮೀನುಗಳ ಸಂತತಿ ಮತ್ತು ಇತರ ಜಲಚರಗಳಿಗೆ ಅಪಾಯಕಾರಿ ಪರಿಸ್ಥಿತಿ ನಿರ್ಮಾಣವಾಗುತ್ತಿದೆ.

11. ಮಾನವ ತನ್ನ ಚಟುವಟಿಕೆಯಿಂದ ಬಿಡುಗಡೆ ಮಾಡುತ್ತಿರುವ ಮೀಥೇನ್, ಕ್ಲೋರೋಫ್ಲೋರೋ ಕಾರ್ಬನ್‌ಗಳು ಹಾಗೂ ಏರೋಸಾಲ್ ಅನಿಲಗಳು ಜಾಗತಿಕ ಉಷ್ಣತೆ ಹೆಚ್ಚಿಸಲು ಕಾರಣವಾಗುತ್ತಿವೆ. ಹವಾನಿಯಂತ್ರಣ, ಶೀತಕಯಂತ್ರಗಳು ಮುಂತಾದವುಗಳಲ್ಲಿ ಬಳಕೆಯಾಗುವ ಈ ಕ್ಲೋರೋಫ್ಲೋರೋ ಕಾರ್ಬನ್‌ಗಳು ವಾತಾವರಣದ ಓಝೋನ್ ರಕ್ಷಾಕವಚವನ್ನು ಹಾಳುಮಾಡುವುದರಿಂದ ಜಾಗತಿಕ ತಾಪಮಾನ ಏರಿಕೆಗೆ ಕಾರಣವಾಗುತ್ತಿದೆ.

12. ಜಾಗತಿಕ ತಾಪಮಾನ ಏರಿಕೆಯ ಪರಿಣಾಮವಾಗಿ ಅಂಟಾರ್ಟಿಕಾ ಪೆನಿನ್ಸುಲಾದಲ್ಲಿರುವ ಅತಿ ದೊಡ್ಡ ಲಾರ್ಸನ್ ಹಿಮಹಲಗೆಯ ಸುಮಾರು 5800 ಚದರ ಕಿ.ಮೀ. ವಿಸ್ತೀರ್ಣದ ದೊಡ್ಡ ಐಸ್ ಬರ್ಗ್ 2017ರಲ್ಲಿ ಒಡೆದು ಬೇರ್ಪಟ್ಟಿತು.

13. ಟಿಬೆಟ್ ಪ್ರಸ್ಥಭೂಮಿಯು ವಿಶ್ವದ ಮೂರನೇ ಅತಿದೊಡ್ಡ ಹಿಮಸಂಗ್ರಹಕಾರಿ ಪ್ರದೇಶವಾಗಿದೆ. ಚೀನಾದ ಪವನಶಾಸ್ತ್ರ ನಿರ್ವಹಣಾ ಸಮಿತಿಯ ಮಾಜೀ ಮುಖ್ಯಸ್ಥರೇ ಹೇಳುವಂತೆ ಚೀನಾದಲ್ಲಿ ಉಳಿದೆಲ್ಲಾ ಪ್ರದೇಶಗಳಿಗಿಂತ ನಾಲ್ಕರಷ್ಟು ವೇಗದಲ್ಲಿ ತಾಪಮಾನ ಹೆಚ್ಚಾಗುತ್ತಿದೆ. ಇದರಿಂದಾಗಿ ಟಿಬೆಟ್‌ನ ಹಿಮನದಿಗಳು ವೇಗವಾಗಿ ಕರಗುತ್ತಿದ್ದು, ಕೆಲವು ಕಾಲಾನಂತರ ಸಿಂಧು, ಗಂಗಾ ಮತ್ತಿತರ ಏಷ್ಯಾದ ನದಿಗಳು ಕಣ್ಮರೆಯಾಗುವ ಭೀತಿಯನ್ನು ಎದುರಿಸುತ್ತಿದ್ದೇವೆ.

14. ಸ್ಟರ್ನ್ ಸಮೀಕ್ಷೆಯ ಪ್ರಕಾರ ವಾತಾವರಣದ ವೈಪರೀತ್ಯದಿಂದಾಗಿ ಪ್ರಾದೇಶಿಕ ಸಮಗ್ರ ಉತ್ಪನ್ನಗಳು 2050ಯ ವೇಳೆಗೆ ಸರಾಸರಿ 8%ರಷ್ಟು ಇಳಿಯುವುದೆಂಬ ಆತಂಕದ ವಿಚಾರವನ್ನು ತಿಳಿಸಿದ್ದಾರೆ. ಮಳೆ ಮಾದರಿಯ ಬದಲಾವಣೆಗಳಿಗೆ ಜಾಗತಿಕ ತಾಪಮಾನ ಹೆಚ್ಚಳವೇ ಕಾರಣ. ಒಟ್ಟಿನಲ್ಲಿ ಕೃಷಿ ಆಧಾರಿತ ಅಭಿವೃದ್ಧಿಯ ರಾಷ್ಟ್ರಗಳು ಜಾಗತಿಕ ತಾಪಮಾನ ಏರಿಕೆಯಿಂದ ಅಪಾಯಕ್ಕೀಡಾಗುವ ಆತಂಕವಿದೆ.

ಸಮುದ್ರದ ಆಮ್ಲೀಯತೆಯನ್ನು ತೆಗೆದುಹಾಕುವ ವಿಧಾನಗಳು

1.ಸಮುದ್ರದ ಜೌಗು ಪ್ರದೇಶಗಳು, ಕಡಲಕಳೆ (Seaweed) ಇವುಗಳು ಇಂಗಾಲವನ್ನು ಹೀರಿಕೊಂಡು ದೀರ್ಘಕಾಲದವರೆಗೆ ಮಣ್ಣಿನಲ್ಲಿ ಸಂಗ್ರಹಿಸಿಡುತ್ತವೆ. 2. ಸಮುದ್ರದ ನೀರಿಗೆ ಸುಣ್ಣದ ಕಲ್ಲು ಮತ್ತು ಸಿಲಿಕೇಟ್‌ನಂತಹ ನೈಸರ್ಗಿಕ ಖನಿಜಗಳನ್ನು ಸೇರಿಸುವುದರಿಂದ, ಸಮುದ್ರದ ಕ್ಷಾರೀಯತೆಯು ಹೆಚ್ಚಾಗಿ, ಇಂಗಾಲವನ್ನು ತಟಸ್ಥಗೊಳಿಸಿ ಆಮ್ಲೀಕರಣವನ್ನು ಕಡಿಮೆ ಮಾಡುತ್ತದೆ.

2. ಕಾಡುಗಳು ಭೂಮಿಯ ಮೇಲಿನ ಕಾರ್ಬನ್‌ಅನ್ನು ಹೀರಿಕೊಳ್ಳುವಂತೆ ಸಮುದ್ರ ಮತ್ತು ಕರಾವಳಿ ಸಸ್ಯಗಳಾದ ಸಾಗರದ ಜೈವಿಕ ಸಂಪನ್ಮೂಲಗಳಾದ ಮ್ಯಾಂಗ್ರೋವ್ ಅಥವಾ ಉಪ್ಪುನೀರಿನ ಮರಗಳು, ಸಮುದ್ರದ ಹುಲ್ಲು ಅಥವಾ ಸೀಗ್ರಾಸ್ ಮತ್ತು ಉಪ್ಪುನೀರಿನ ಜವುಗು ಪ್ರದೇಶಗಳು ಇಂಗಾಲದ ಡೈಆಕ್ಸೈಡ್‌ಅನ್ನು ದ್ಯುತಿಸಂಶ್ಲೇಷಣೆಯಿಂದ ಹೀರಿಕೊಳ್ಳುತ್ತವೆ. ಸಸ್ಯಗಳು ಸತ್ತಾಗ ಅವುಗಳ ಬೇರುಗಳು ಮತ್ತು ಎಲೆಗಳು ಸಮುದ್ರದ ತಳದ ಕೆಸರಿನಲ್ಲಿ ಹೂತು ಅಲ್ಲಿ ಆಮ್ಲಜನಕದ ಕೊರತೆಯಿಂದಾಗಿ ಇಂಗಾಲವು ವಾತಾವರಣಕ್ಕೆ ಬಿಡುಗಡೆಯಾಗದೆ, ನೂರಾರು ವರ್ಷಗಳ ಕಾಲ ಕೆಸರಿನಲ್ಲೇ ಸಂಗ್ರಹವಾಗುತ್ತವೆ. ಇದನ್ನು ನೀಲಿ ಇಂಗಾಲ ಅಥವಾ ಬ್ಲೂ ಕಾರ್ಬನ್ ಎನ್ನುತ್ತಾರೆ. ಇದರಿಂದಾಗಿ ಇಂಗಾಲವು ಶಾಶ್ವತವಾಗಿ ಸಮುದ್ರದ ತಳದಲ್ಲಿ ಸಂಗ್ರಹವಾಗುತ್ತದೆ.

ಮ್ಯಾಂಗ್ರೋವ್ ಕಾಡುಗಳು (ಕಂಡ್ಲಾ ಕಾಡುಗಳು) ನೀಲಿ ಇಂಗಾಲದ ಅತಿ ದೊಡ್ಡ ಸಂಗ್ರಹಾಗಾರವೆAದೇ ಹೇಳಬಹುದು. ಇವು ಪ್ರಪಂಚದ ಉಷ್ಣವಲಯದ ಕಾಡುಗಳಲ್ಲಿ ಬಹು ಕಡಿಮೆ ಭಾಗವನ್ನು ಹೊಂದಿದ್ದರೂ, ಹೆಚ್ಚು ಇಂಗಾಲವನ್ನು ಸಂಗ್ರಹಿಸುವ ಪರಿಸರ ವ್ಯವಸ್ಥೆಗಳಲ್ಲಿ ಒಂದಾಗಿದೆ. ಮ್ಯಾಂಗ್ರೋವ್ ಸಸ್ಯಗಳು ಭೂಮಿಯ ಮೇಲಿನ ಕಾಡುಗಳಿಗಿಂತ ವಿಭಿನ್ನವಾಗಿದ್ದು ಹೆಚ್ಚು ಪರಿಣಾಮಕಾರಿಯಾಗಿ ಇಂಗಾಲದ ಡೈಆಕ್ಸೈಡ್‌ಅನ್ನು ನಿಯಂತ್ರಿಸುತ್ತದೆ.

ಸಾಮಾನ್ಯವಾಗಿ ಭೂಮಿಯಲ್ಲಿರುವ ಕಾಡುಗಳಲ್ಲಿ ಸಸ್ಯಗಳು ಸತ್ತಾಗ ಅವು ಗಾಳಿಯಲ್ಲಿರುವ ಆಮ್ಲಜನಕವನ್ನು ಉಪಯೋಗಿಸಿಕೊಂಡು ಕೊಳೆತು ಇಂಗಾಲವನ್ನು ಪುನಃ ವಾತಾವರಣಕ್ಕೆ ಬಿಡುತ್ತವೆ. ಆದರೆ ಈ ಮ್ಯಾಂಗ್ರೋವ್ ಗಿಡಗಳು ಉಪ್ಪುನೀರಿನಲ್ಲಿರುವುದರಿಂದ ಸಸ್ಯಗಳ ಕೊಳೆಯುವ ಪ್ರಕ್ರಿಯೆ ಅತಿ ನಿಧಾನವಾಗಿರುತ್ತದೆ. ಇವು ಇಂಗಾಲವನ್ನು ಆರು ಮೀಟರ್‌ವರೆಗೂ ಹೆಚ್ಚಿನ ಆಳದಲ್ಲಿ ತಮ್ಮ ಬೇರುಗಳ ಮೂಲಕ ಅತಿ ಹೆಚ್ಚಿನ ಪ್ರಮಾಣದ ಇಂಗಾಲವನ್ನು ಸಾವಿರಾರು

ವರ್ಷಗಳ ಕಾಲ ಸಂಗ್ರಹಿಸುತ್ತವೆ. ಆದರೆ ಭೂಮಿಯ ಕಾಡುಗಳಲ್ಲಿ ಮರಗಳು ಎಲೆ ಮತ್ತು ಕಾಂಡಗಳಲ್ಲಿ ಇಂಗಾಲವನ್ನು ಸಂಗ್ರಹಿಸುತ್ತವೆ. ಈ ಮ್ಯಾಂಗ್ರೋವ್ ಕಾಡುಗಳು ಸುಮಾರು ಒಂದು ಹೆಕ್ಟೇರ್‌ಗೆ ಸಾವಿರ ಟನ್‌ಗಳಿಗಿಂತ ಹೆಚ್ಚು ಇಂಗಾಲವನ್ನು ಸಂಗ್ರಹಿಸಿಡುವ ಸಾಮರ್ಥ್ಯವನ್ನು ಹೊಂದಿರುತ್ತವೆ. ಆದರೆ ಭೂಮಿಯ ಮೇಲಿನ ಕಾಡುಗಳ ಸಾಮರ್ಥ್ಯ ಗಣನೀಯವಾಗಿ ಕಡಿಮೆ ಇರುತ್ತದೆ.

ಮ್ಯಾಂಗ್ರೋವ್ ಕಾಡುಗಳು ಪರಿಸರ ಇಂಗಾಲದ ನಿಯಂತ್ರಣದ ಜೊತೆಗೆ ಕರಾವಳಿಗೆ ದೊಡ್ಡ ರಕ್ಷಣಾ ಕವಚದಂತಿದೆ. ಇವುಗಳ ದಟ್ಟವಾದ ಬೇರುಗಳು ಸಮುದ್ರದ ಅಲೆಗಳ ತೀವ್ರತೆಯನ್ನು 90% ನಷ್ಟು ಕಡಿಮೆಮಾಡುವುದರಿಂದ ಇವು ಚಂಡಮಾರುತ ಮತ್ತು ಸುನಾಮಿಗಳಿಂದ ಜನರನ್ನು ಬಹುಮಟ್ಟಿಗೆ ರಕ್ಷಿಸುತ್ತವೆ. ಮಾನವ ಹಸ್ತಕ್ಷೇಪದಿಂದ ಈ ಮ್ಯಾಂಗ್ರೋವ್ ನಾಶವಾದರೆ ಪುನಃ ಅದನ್ನು ನಿರ್ಮಿಸುವುದು ಕಷ್ಟಸಾಧ್ಯ. ಆದ್ದರಿಂದ ಮ್ಯಾಂಗ್ರೋವ್ ಕಾಡುಗಳನ್ನು ರಕ್ಷಿಸಬೇಕಾಗಿದೆ.

3. ವಾತಾವರಣದಲ್ಲಿರುವ ಕೃತಕ ಅಪ್‌ವೆಲ್ಲಿಂಗ್: ಸಮುದ್ರದ ಆಳದಲ್ಲಿರುವ ನೀರಿನಲ್ಲಿ ಸಾರಜನಕ, ರಂಜಕ, ಕಬ್ಬಿಣ ಮುಂತಾದ ಪೋಷಕಾಂಶಗಳುಳ್ಳ ನೀರನ್ನು ಕೃತಕ ಪಂಪ್‌ಗಳ ಮೂಲಕ ಮೇಲ್ಮೈಗೆ ತರುವ ತಂತ್ರಜ್ಞಾನವೇ ಕೃತಕ ಅಪ್‌ವೆಲ್ಲಿಂಗ್. ಈ ಮೇಲ್ಮೈಗೆ ಬಂದ ಪೋಷಕಾಂಶಗಳಿಂದ ಕಡಲ ಪಾಚಿಗಳು ಮತ್ತು ಸಸ್ಯಪ್ಲಾಂಕ್ಟನ್ ಬೆಳೆದು ನೀರಿನಲ್ಲಿರುವ ಇಂಗಾಲದ ಡೈಆಕ್ಸೆöÊಡ್‌ಅನ್ನು ಹೀರಿಕೊಳ್ಳುತ್ತವೆ. ಈ ಸಸ್ಯಗಳು ಸತ್ತನಂತರ ಅವು ತಾವು ಹೀರಿಕೊಂಡ ಇಂಗಾಲದೊAದಿಗೆ ಸಮುದ್ರದ ತಳದಲ್ಲಿ ಮುಳುಗಿದ್ದು ಶಾಶ್ವತವಾಗಿ ಇಂಗಾಲವು ಅಲ್ಲಿ ಶೇಖರಣೆಯಾಗಿರುತ್ತದೆ. ಈ ನೀರು ಹವಳದ ದಿಬ್ಬಗಳನ್ನೂ ನಾಶವಾಗದಂತೆ ರಕ್ಷಿಸುತ್ತದೆ. ಆದರೆ ಈ ಕೃತಕ ಅಪ್‌ವೆಲ್ಲಿಂಗ್ ವಿಧಾನವು ಹೆಚ್ಚಿನ ದುಬಾರಿಯದಾಗಿದೆ.

ಸಾಗರ ಇಂಗಾಲದ ಚಕ್ರ: ಇದು ಮೂಲಭೂತವಾದ ಇಂಗಾಲ ಚಕ್ರ. ಸಾಗರಗಳು ತಾವು ಹೊರಸೂಸುವುದಕ್ಕಿಂತ ಹೆಚ್ಚಿನ ಇಂಗಾಲವನ್ನು ಹೀರಿಕೊಳ್ಳತ್ತವೆ. ಆದ್ದರಿಂದ ಇದನ್ನು 'ಕಾರ್ಬನ್ ಸಿಂಕ್' ಎಂದು ಕರೆಯಲಾಗಿದೆ. ಸಮುದ್ರ ಜೀವಿಗಳು ಇಂಗಾಲವನ್ನು ಶೆಲ್ (ಚಿಪ್ಪು) ರೂಪದಲ್ಲಿ ಕ್ಯಾಲ್ಸಿಯಂ ಕಾರ್ಬೋನೇಟ್ ಆಗಿ ಪರಿವರ್ತಿಸುತ್ತವೆ. ಈ ಜೀವಿಗಳು ಅವುಗಳಿಂದ ಹೊರಬಂದಾಗ ಈ ಶೆಲ್‌ಗಳು ಸಮುದ್ರದ ತಳದಲ್ಲಿ ಸಂಗ್ರಹವಾಗಿ ಅಂತಿಮವಾಗಿ ಅಲೆಗಳಿಂದ ಒಡೆದು ಅಪಾರ ಒತ್ತಡದಿಂದ ಸುಣ್ಣದ ಕಲ್ಲುಗಳಾಗಿ ರೂಪುಗೊಳ್ಳುತ್ತವೆ. ಇವುಗಳನ್ನು ಗಾಳಿಗೆ ಒಡ್ಡಿದಾಗ ಹವಾಮಾನಕ್ಕೆ ಒಳಗಾಗಿ ಇಂಗಾಲದ ಡೈಆಕ್ಸೈಡ್ ವಾತಾವರಣಕ್ಕೆ ಬಿಡುಗಡೆಯಾಗುತ್ತವೆ. ಹೀಗೆ ಆಮ್ಲಜನಕ ಮತ್ತು ಸಾರಜನಕ ಚಕ್ರಗಳ ಜೊತೆಗೆ ಇಂಗಾಲದ ಚಕ್ರವು ಜೀವರಾಶಿಯ ಅಸ್ತಿತ್ವದಲ್ಲಿ ಮುಖ್ಯಪಾತ್ರ ವಹಿಸುತ್ತದೆ.

ಸಾಗರ ಇಂಗಾಲ ಚಕ್ರವು ಭೂಮಿಯ ವಾತಾವರಣ, ಸಾಗರ ಮತ್ತು ಜೀವಿಗಳ ನಡುವೆ ಇಂಗಾಲದ ಡೈಆಕ್ಸೈಡ್ ವರ್ಗಾವಣೆಯಾಗುವ ಪ್ರಕ್ರಿಯೆಯಾಗಿದೆ. ಸಾಗರವು ಇಂಗಾಲದ ಅತಿ ದೊಡ್ಡ ಸಂಗ್ರಹಾಲಯಗಳಲ್ಲಿ ಒಂದಾಗಿದೆ. ಇದು ಜಾಗತಿಕ ಹವಾಮಾನವನ್ನು ನಿಯಂತ್ರಿಸುವಲ್ಲಿ ಪ್ರಮುಖ ಪಾತ್ರ ವಹಿಸುತ್ತದೆ. ಸಾಗರದ ಇಂಗಾಲದ ಚಕ್ರದ ಪ್ರಮುಖ ಹಂತಗಳು ಹೀಗಿವೆ.

೧ ವಾತಾವರಣದೊಂದಿಗೆ ಇಂಗಾಲದ ವಿನಿಮಯ (Air-sea exchange): ಸಾಗರವು ಇಂಗಾಲದ ಡೈಆಕ್ಸೈಡ್‌ಅನ್ನು ವಾತಾವರಣದಿಂದ ನೇರವಾಗಿ ಹೀರಿಕೊಳ್ಳುತ್ತದೆ. ತಣ್ಣೀರು ಬೆಚ್ಚಗಿನ ನೀರಿಗಿಂತ ಹೆಚ್ಚು ಇಂಗಾಲದ ಡೈಆಕ್ಸೈಡ್‌ಅನ್ನು ಹೀರಿಕೊಳ್ಳುತ್ತದೆಯಾದ್ದರಿಂದ ಧ್ರುವ ಪ್ರದೇಶಗಳಲ್ಲಿ ಇಂಗಾಲದ ಹೀರಿಕೊಳ್ಳುವಿಕೆ ಹೆಚ್ಚಾಗಿರುತ್ತದೆ.

೨ ಸಮುದ್ರದ ತಳದಲ್ಲಿ ಇಂಗಾಲದ ಸಂಗ್ರಹಣೆ: ಜೈವಿಕ ಇಂಗಾಲದ ಪ್ರತ್ಯೇಕತೆಯು ಇಂಗಾಲದ ಚಕ್ರದ ಭಾಗವಾಗಿ ನೈಸರ್ಗಿಕವಾಗಿ ಸಂಭವಿಸುವ ಪ್ರಕ್ರಿಯೆಯಾಗಿದೆ. ಇದನ್ನು ಇಂಗಾಲದ ಕೃಷಿ ಎಂದು ಕರೆಯಲಾಗಿದೆ.

ಸಾಗರದ ಮೇಲ್ಮೈಯಲ್ಲಿರುವ ಸಣ್ಣ ಫೈಟೋಪ್ಲಾಂಕ್ಟನ್ ಸಸ್ಯಗಳು ದ್ಯುತಿಸಂಶ್ಲೇಷಣ ಪ್ರಕ್ರಿಯೆಯ ಮೂಲಕ ಇಂಗಾಲವನ್ನು ಜೈವಿಕ (organic) ಮತ್ತು ಅಜೈವಿಕ (inorganic) ಇಂಗಾಲವಾಗಿ ಪರಿವರ್ತಿಸುತ್ತದೆ. ಜೈವಿಕ ಇಂಗಾಲವು ಸತ್ತ ಪ್ರಾಣಿ ಮತ್ತು ಸಸ್ಯಗಳ ಅವಶೇಷಗಳಿಂದ ಉಂಟಾಗಿ ಸಾಗರದ ಮೇಲ್ಮೈಯಿಂದ ಆಳಕ್ಕೆ ಇಳಿಯುತ್ತವೆ. ಅಜೈವಿಕ ಇಂಗಾಲವು ಮುಖ್ಯವಾಗಿ ಸಾಗರ ಜೀವಿಗಳ ಚಿಪ್ಪುಗಳು ಮತ್ತು ಅಸ್ಥಿಪಂಜರದಲ್ಲಿರುವ ಕ್ಯಾಲ್ಸಿಯಂ ಕಾರ್ಬೋನೇಟ್‌ನಿಂದ ಕೂಡಿರುತ್ತವೆ. ಈ ಇಂಗಾಲದ ರೂಪಗಳು ದೀರ್ಘ ಕಾಲದವರೆಗೆ ಅಂದರೆ ಅನೇಕ ಲಕ್ಷ ವರ್ಷಗಳ ವರೆಗೆ ಸಮುದ್ರದ ತಳದಲ್ಲಿ ಸಂಗ್ರಹವಾಗಬಲ್ಲುದು.

೩ ಭೌತಿಕ ಇಂಗಾಲದ ಪಂಪ್: ಹೆಚ್ಚಿನ ಇಂಗಾಲವು ಸಮುದ್ರದ ನೀರಿನಲ್ಲಿ ಕರಗಿದ ಇಂಗಾಲದ ರೂಪದಲ್ಲಿರುತ್ತದೆ. ತಂಪಾದ ನೀರಿನಲ್ಲಿ ಇಂಗಾಲವನ್ನು ಮೇಲ್ಮೈಯಿಂದ ಸಾಗರದ ತಳಕ್ಕೆ ಸಾಗಿಸುತ್ತದೆ. ಸಾಗರವು ಮಾನವ ಚಟುವಟಿಕೆಗಳಿಂದ ಉತ್ಪತ್ತಿಯಾಗುವ ಸುಮಾರು ನಾಲ್ಕನೇ ಒಂದು ಭಾಗದಷ್ಟು ಇಂಗಾಲದ ಡೈಆಕ್ಸೈಡ್‌ಅನ್ನು ಹೀರಿಕೊಳ್ಳುತ್ತದೆ. ಇದರಿಂದಾಗಿ ವಾತಾವರಣದ ಇಂಗಾಲದ ಪ್ರಮಾಣವು ಕಡಿಮೆಯಾಗುವುದರ ಮೂಲಕ ಜಾಗತಿಕ ತಾಪಮಾನವನ್ನು ತಗ್ಗಿಸಲು ಸಹಕಾರಿಯಾಗಿದೆ. ಆದರೆ ಸಾಗರವು ಅತಿಯಾದ ಇಂಗಾಲದ ಡೈಆಕ್ಸೈಡ್‌ಅನ್ನು ಹೀರಿಕೊಳ್ಳುವುದರಿಂದ ಸಮುದ್ರದ ನೀರು ಹೆಚ್ಚು ಆಮ್ಲೀಯವಾಗಿ ಸಾಗರ ಜೀವಿಗಳು, ಹವಳ, ಚಿಪ್ಪುಜೀವಿಗಳ, ಅಳಿವಿಗೆ ಕಾರಣವಾಗಿದೆ.

ಇಂಗಾಲದ ಚಕ್ರದ ಮಹತ್ವ: ವಾತಾವರಣದಲ್ಲಿ ಇಂಗಾಲದ ಡೈಆಕ್ಸೈಡ್ ಸಣ್ಣ ಪ್ರಮಾಣದಲ್ಲಿ ಕಂಡುಬAದರೂ, ಅದು ಶಕ್ತಿಯನ್ನು ಸಮತೋಲನಗೊಳಿಸುವಲ್ಲಿ ಮುಖ್ಯಪಾತ್ರ ವಹಿಸುತ್ತದೆ. ಇಂಗಾಲವು ಭೂಮಿಯ ಪ್ರತಿಯೊಂದು ಜೀವರಾಶಿಯ ಅವಿಭಾಜ್ಯ ಅಂಗವಾಗಿದೆ. ಪ್ರೋಟೀನ್‌ಗಳಿಂದ ಹಿಡಿದು ಡಿ ಎನ್ ಎ ವರೆಗೆ ಇಂಗಾಲದ ಸಾವಯವ ಸಂಯುಕ್ತವಾಗಿವೆ. ಆಮ್ಲಜನಕ ಮತ್ತು ಸಾರಜನಕ ಚಕ್ರಗಳ ಜೊತೆಗೆ ಇಂಗಾಲದ ಚಕ್ರವು ಜೀವರಾಶಿಯ ಅಸ್ತಿತ್ವದಲ್ಲಿ ಮುಖ್ಯಪಾತ್ರ ವಹಿಸುತ್ತದೆ.

ಒಟ್ಟಿನಲ್ಲಿ ಕ್ರಯೋಸ್ಫಿಯರ್ ಬದಲಾವಣೆಗಳಿಂದ ಸಮುದ್ರಮಟ್ಟ ಏರಿಕೆ, ಜಲಸಂಪನ್ಮೂಲಗಳ ಮೇಲೆ ಪರಿಣಾಮ, ಪರಿಸರ ಜೀವ ವೈವಿಧ್ಯತೆ, ಮಾನವನ ದಿನ ನಿತ್ಯಜೀವನದ ಮೇಲೆ ಅಗಾಧ ಪರಿಣಾಮ ಬೀರಲಿದೆ. ಐಪಿಸಿಸಿಯ ಮುಖ್ಯ ಎಚ್ಚರಿಕೆ ಎಂದರೆ

ಕ್ರಯೋಸ್ಫಿಯರ್ ವೇಗವಾಗಿ ಬದಲಾಗುತ್ತಿರುವುದರಿಂದ ವಾತಾವರಣದ ಹಸಿರುಮನೆ ಅನಿಲಗಳನ್ನು ಕಡಿಮೆ ಮಾಡದಿದ್ದರೆ ಪರಿಸ್ಥಿತಿ ಗಂಭೀರವಾಗುತ್ತದೆ ಎಂಬ ಹೇಳಿಕೆ ನೀಡಿದೆ.

ಸಾಗರಗಳಲ್ಲಿ ಜಾಗತಿಕ ತಾಪಮಾನದ ನಿವಾರಣೋಪಾಯ:

ಯು ಎನ್ ಎಫ್ ಸಿ ಸಿ ಸಿ ತಿದ್ದುಪಡಿ ಮಾಡಿದ ಕ್ಯೂಟೋ ನಿಯಮಾವಳಿಗಳನ್ನು 160 ಕ್ಕೂ ಹೆಚ್ಚಿನ ರಾಷ್ಟಗಳು ಪಾಲಿಸುತ್ತಿವೆ. ಇದರಿಂದಾಗಿ ಹಸಿರುಮನೆ ಅನಿಲದ ಹೊರಸೂಸುವಿಕೆಯನ್ನು ತಡೆಹಿಡಿಯುವ ಯೋಜನೆಯಲ್ಲಿ 2030ರೊಳಗೆ 42% ಜಾಗತಿಕ ಹಸಿರುಮನೆ ಅನಿಲವನ್ನು ನಿಯಂತ್ರಿಸುವ ಮತ್ತು 2025ರೊಳಗೆ 55% ಹಸಿರುಮನೆ ಅನಿಲಗಳನ್ನು ತಡೆಹಿಡಿಯುವ ಯೋಜನೆ ಇದೆ. ಜಾಗತಿಕ ತಾಪಮಾನದೊಂದಿಗೆ ಹೊಂದಿಕೊಳ್ಳಲು ವಾತಾವರಣಕ್ಕೆ ಅನುಕೂಲವಾದ ಉಪಕರಣವನ್ನು ಉಪಯೋಗಿಸುವುದು, ಸಮುದ್ರಮಟ್ಟದ ಏರಿಕೆಯಿಂದ ತೊಂದರೆಯಾಗಬಲ್ಲ ನಿರ್ಮಾಣಗಳನ್ನು ತಡೆಯುವುದು, ಮುಂತಾದ ಯೋಜನೆಗಳನ್ನು ಹಾಕಿಕೊಳ್ಳಬೇಕು. ಭೂ-ವಾಸ್ತುಶಿಲ್ಪವೆಂದರೆ ಭೂಮಿಯ ನೈಸರ್ಗಿಕ ಪರಿಸರವನ್ನು ಬೃಹತ್ ಪ್ರಮಾಣದಲ್ಲಿ ಮಾನವನ ಅಗತ್ಯಗಳಿಗೆ ಮಾರ್ಪಡಿಸುವುದಾಗಿದೆ, ಇದನ್ನು ಅಳವಡಿಸಿಕೊಳ್ಳಬೇಕು.

ಭಾರತದ ಕರಾವಳಿ ಪ್ರದೇಶದಲ್ಲಿ ಸಮುದ್ರಮಟ್ಟ ಏರಿಕೆ: ಭಾರತದ ಕರಾವಳಿಗಳಲ್ಲಿ ಕಳೆದ ೫೦ ವರ್ಷಗಳಲ್ಲಿ ಸಮುದ್ರುಮಟ್ಟವು 8.5 ಸೆಂ.ಮೀ. ಏರಿಕೆಯಾಗಿದೆ, ಸರಾಸರಿ ಪ್ರತಿವರ್ಷವೂ 1.7 ಮಿ.ಮೀ. ಎಂಬ ಎಚ್ಚರಿಕೆಯ ಸಂಗತಿಯನ್ನು ಕೇಂದ್ರ ಸರಕಾರ ಬಹಿರಂಗಪಡಿಸಿದೆ. ಶತಮಾನದಂಚಿಗೆ ಜಲಪ್ರಳಯವಾಗಿ ಭಾರತದ ಮೂರು-ನಾಲ್ಕು ನಗರಗಳ ಕೆಲವು ಪ್ರದೇಶಗಳನ್ನು ಆವರಿಸಬಹುದೆಂಬ ಅಪಾಯಕಾರಿ ಭೀತಿಯನ್ನು ಎದುರಿಸುತ್ತಿದ್ದೇವೆ. ಪಶ್ಚಿಮ ಬಂಗಾಳದ ಡೈಮಂಡ್ ಹಾರ್ಬರ್, ಹಲ್ದಿಯಾ, ಗುಜರಾತ್‌ನ ಕಾಂಡ್ಲಾ, ಪೋರ್ಟ್ಬ್ಲೇರ್ ಮೊದಲಾದ ಬಂದರು ಪ್ರದೇಶಗಳಲ್ಲಿ ಕಡಲು ಕೊರೆತದಿಂದ ಸಮುದ್ರಮಟ್ಟ ಏರಕೆಯಾಗಿದೆ ಎಂದು ತಿಳಿಸಲಾಗಿದೆ.

ಇಂಗಾಲಾಮ್ಲದ ಹೊರಸೂಸುವಿಕೆಯನ್ನು ತಡೆಯದಿದ್ದರೆ 2100ರ ಹೊತ್ತಿಗೆ ಪ್ರತಿವರ್ಷವೂ ಒಂದು ಮೀಟರ್ ಸಮುದ್ರುಮಟ್ಟ ಏರಿಕೆಯಾಗಲಿದೆ ಎಂದು ವಿಶ್ವಸಂಸ್ಥೆ ಎಚ್ಚರಿಕೆ ನೀಡಿದೆ. ಜಾಗತಿಕ ತಾಪಮಾನದಿಂದಾಗಿ ಇನ್ನು ಹತ್ತೇ ವರ್ಷಗಳಲ್ಲಿ ಬ್ಯಾಂಕಾಕ್ ಮುಳುಗಡೆ ಭೀತಿಯಿದೆ ಎಂದು ಎಚ್ಚರಿಕೆ ನೀಡಿದೆ.

ಜಪಾನ್, ಚೀನಾ, ಬಾಂಗ್ಲಾದೇಶ್‌ಗಳಲ್ಲಿಯೂ ಹವಾಮಾನ ವೈಪರೀತ್ಯದಿಂದಾಗಿ ಸಮುದ್ರಮಟ್ಟ ಏರಿಕೆಯಾಗುವ ಸಾಧ್ಯತೆ ಹೆಚ್ಚು ಎಂದು ಯು ಎನ್ ಸೆಕ್ರೆಟರಿ ಜನರಲ್ ತೀವ್ರ ಕಳವಳ ವ್ಯಕ್ತಪಡಿಸಿದ್ದಾರೆ. ಅವರು ಏಷಿಯನ್ ಶೃಂಗಸಭೆಯಲ್ಲಿ ಪಾಲ್ಗೊಳ್ಳುತ್ತಾ ಮಾತನಾಡಿ ಹವಾಮಾನ ವೈಪರೀತ್ಯದಿಂದಾಗಿ ಮುನ್ಸೂಚನೆಗಿಂತ ಮುಂಚಿತವಾಗಿಯೇ ಸಾಗರಗಳ ಮಟ್ಟವು ವೇಗವಾಗಿ ಏರುತ್ತಿದೆ ಎಂದು ಸಂಶೋಧನಾ ಕೇಂದ್ರದ ವರದಿಯೊಂದು ಉಲ್ಲೇಖಿಸಿದೆ. 2050ರ ವೇಳೆಗೆ 300ದಶಲಕ್ಷ ಜನರು ಸಮುದ್ರ ನೀರಿನ ಪ್ರವಾಹಕ್ಕೆ ಒಳಗಾಗುತ್ತಾರೆ ಎಂದು ಸಂಶೋಧನೆ ಮುನ್ಸೂಚನೆ ನೀಡಿದೆ ಎಂದು ಎಚ್ಚರಿಸಿದ್ದಾರೆ. ಈ ಕುರಿತು ಇತ್ತೀಚೆಗೆ ಅಧ್ಯಯನ ನಡೆಸಿದ್ದ ಕ್ಲೈಮೇಟ್ ಸೆಂಟ್ರಲ್ ಸಂಸ್ಥೆ, ನೇಚರ್ ಕಮ್ಯುನಿಕೇಷನ್ಸ್ ಜರ್ನಲ್‌ನಲ್ಲಿ ಪ್ರಕಟಿಸಿರುವ ಅಂಕಿ ಅಂಶಗಳನ್ನು ಗಮನಿಸಿದರೆ ಹವಾಮಾನ ಬದಲಾವಣೆಯಿಂದ ಜಾಗತಿಕ ತಾಪಮಾನವು ನಮ್ಮ ಊಹೆಗೂ ಮೀರಿದ ವೇಗದಲ್ಲಿ ಓಡುತ್ತಿದೆ, ಇದನ್ನೆಲ್ಲಾ ಗಮನಿಸಿದರೆ ನಮ್ಮ ಭೂಮಿಗೆ ದೊಡ್ಡ ಅಪಾಯವಿದೆ ಎಂಬುದು ಸ್ಪಷ್ಟವಾಗುತ್ತದೆ ಎಂದು ಯು ಎನ್ ಸೆಕ್ರೆಟರಿ ಜನರಲ್ ಕಳವಳ ವ್ಯಕ್ತಪಡಿಸಿದ್ದಾರೆ.

ಈ ಕುರಿತು ಸಂಯುಕ್ತ ರಾಷ್ಟ್ರ ಸಂಸ್ಥೆಯು ಬದ್ಧವಾಗಿದ್ದು, ಈಗಾಗಲೇ ವಿಜ್ಞಾನಿಗಳು ಹೇಳಿರುವಂತೆ ಈ ಶತಮಾನದ ಅಂತ್ಯದ ವೇಳೆಗೆ 1.5 ಡಿಗ್ರಿ ಸೆಲ್ಸಿಯಸ್‌ನಷ್ಟು ಹೆಚ್ಚುತ್ತಿರುವ ತಾಪಮಾನದಲ್ಲಿ ಕೈಗೊಳ್ಳಬೇಕಾದ ತುರ್ತು ಕ್ರಮಗಳನ್ನು ಅನುಸರಿಸುವಲ್ಲಿ ಜಾಗತಿಕವಾಗಿ ಸರ್ಕಾರಗಳು, ಕೈಗಾರಿಕೆ, ವ್ಯಾಪಾರ ಸಮುದಾಯ ಗಮನಹರಿಸಲು ಮುಂದಾಗಲು ಚಿಂತಿಸಿವೆ. ಇದು ಸಾಧ್ಯವಾಗಬೇಕಾದರೆ 2050ರ ವೇಳೆಗೆ ಹಸಿರುಮನೆಗೆ ಮತ್ತು ಸಾಗರಕ್ಕೆ ಸೇರುವ ಇಂಗಾಲ ತಟಸ್ಥವಾಗಬೇಕು. ಇದಕ್ಕಾಗಿ ಮುಂದಿನ ದಶಕಗಳಲ್ಲಿ ಇಂಗಾಲ ಮುಂತಾದ ಹಸಿರುಮನೆ ಅನಿಲಗಳ ಹೊರಸೂಸುವಿಕೆಯನ್ನು 45%ರಷ್ಟು ಕಡಿಮೆಗೊಳಿಸಬೇಕು. ಇದಕ್ಕಾಗಿ ಎಲ್ಲ ರಾಷ್ಟ್ರಗಳು 1. ಇಂಗಾಲದ ಟ್ರೇಡಿಂಗ್ ಬೆಲೆ ನಿಗದಿಪಡಿಸಬೇಕು 2. ಪಳಯುಳಿಕೆ ಇಂಧನಗಳಿಗೆ ಸಬ್ಸಿಡಿಗಳನ್ನು ನಿಲ್ಲಿಸಬೇಕು. 3. ಭವಿಷ್ಯದಲ್ಲಿ ಕಲ್ಲಿದ್ದಲನ್ನು ಆಧರಿಸಿದ ಹೊಸ ವಿದ್ಯುತ್ ಸ್ಥಾವರ ನಿರ್ಮಾಣವನ್ನು ನಿರ್ಬಂಧಿಸಬೇಕು 4. ಹವಾಮಾನ ಬದಲಾವಣೆಗೆ ಸಂಬAಧಿಸಿದAತೆ ರಾಷ್ಟ್ರಗಳು ಕಲ್ಲಿದ್ದಲಿನ ಅತಿಯಾದ ಅವಲಂಬನೆಯಿAದ ಹೊರಬರಬೇಕಾಗಿದೆ ಎಂದು ಹೇಳಿದ್ದಾರೆ.

ಭವಿಷ್ಯದಲ್ಲಿ ಸಮುದ್ರ ಮಟ್ಟ ಮತ್ತು ಜಾಗತಿಕ ಹವಾಮಾನ ಏರಿಕೆ: 1955ರಿಂದಲೂ ಸಮುದ್ರದ ಉಷ್ಣಾಂಶವನ್ನು ಅಳೆಯುತ್ತಿದ್ದು, 2023ರಲ್ಲಿ ಜಾಗತಿಕವಾಗಿ ಸಮುದ್ರದ ಮೇಲ್ಮೈಯ ಉಷ್ಣಾಂಶವು ಸರಾಸರಿಗಿಂತ 0.99 ಡಿಗ್ರಿ ಸೆಲ್ಸಿಯಸ್ ಹೆಚ್ಚಾಗಿರುವುದು ಕಂಡುಬAದಿದೆ.

ಇಪ್ಪತ್ತು ಸಾವಿರ ವರ್ಷಗಳಿಂದಲೂ ಸಮುದ್ರಮಟ್ಟದಲ್ಲಿ ಏರಿಕೆ ಕಂಡುಬರುತ್ತಿದೆಯಾದರೂ, 1901ರಿಂದ 2018ರ ತನಕ ಸರಾಸರಿ ಸಮುದ್ರಮಟ್ಟವು 15ರಿಂದ 25 ಸೆಂ.ಮೀ. ಏರಿಕೆಯಾಗಿದೆ. ಇದು ಕಳೆದ 3000 ವರ್ಷಗಳಲ್ಲಿ ಸಮುದ್ರ ಮಟ್ಟ ಏರಿಕೆಯಾದ ವೇಗಕ್ಕಿಂತ ಹೆಚ್ಚಾಗಿದೆ. ಸಾಮಾನ್ಯವಾಗಿ ಧ್ರುವ ಪ್ರದೇಶಗಳಲ್ಲಿ ಚಳಿಗಾಲದಲ್ಲಿ ತೀವ್ರ ಪ್ರಮಾಣದಲ್ಲಿ ಮಂಜುಗಡ್ಡೆ ಬೆಳೆದು ಬೇಸಿಗೆಯಲ್ಲಿ ಕರಗುತ್ತದೆ. ಆದರೆ ಹವಾಮಾನ ಬದಲಾವಣೆಯಿಂದಾಗಿ ಪ್ರತಿವರ್ಷ ಕರಗುವ ಪ್ರಮಾಣ ಹೆಚ್ಚುತ್ತಿದೆ. ಉಪಗ್ರಹಗಳ ಅಂಕಿ ಅಂಶಗಳ ಪ್ರಕಾರ ಪ್ರತಿ ದಶಕಕ್ಕೆ ಹಿಮನದಿಗಳು ಕರಗುವುದು ಧ್ರುವಸಮೀಪದ ಸಮುದ್ರದ ಮೇಲಿನ ಮಂಜುಗಡ್ಡೆಗಳು ಕರಗುವುದರಿಂದ ಸುಮಾರು 12.8% ರಷ್ಟು ಮಂಜುಗಡ್ಡೆ ಕಡಿಮೆಯಾಗುತ್ತಿದೆ. ಹಳೆಯ ಮಂಜುಗಡ್ಡೆ ಪದರಗಳು ಕರಗಿಹೋಗಿ ಹೊಸ ತೆಳುವಾದ ಪದರಗಳು ರೂಪುಗೊಳ್ಳುತ್ತಿವೆ.

ಅಲ್ಬೆಡೋ ಪರಿಣಾಮ ಹವಾಮಾನ ವಿಜ್ಞಾನದಲ್ಲಿ ಮುಖ್ಯ ಪರಿಕಲ್ಪನೆ. ಧ್ರುವ ಪ್ರದೇಶಗಳಲ್ಲಿ ಮಂಜುಗಡ್ಡೆಗಳು ಕರಗುವುದನ್ನು ಸ್ವಲ್ಪ ಮಟ್ಟಿಗೆ ನಿಯಂತ್ರಿಸಲು ಅಲ್ಬೆಡೋ ಪರಿಣಾಮ ಕಾರಣವಾಗಿದೆ. ಸೂರ್ಯನಿಂದ ಭೂಮಿಯ ಮೇಲೆ ಬೀಳುವ ಬೆಳಕು ಮತ್ತು ಶಾಖ ಒಂದೇ ರೀತಿ ಇರುವುದಿಲ್ಲ. ಮಂಜುಗಡ್ಡೆ ಬೆಳ್ಳಗಿರುವುದರಿಂದ ಅದು ಸೂರ್ಯನ ಬೆಳಕಿನ ಬಹು ಭಾಗವನ್ನು (90% ರಷ್ಟು) ಬಾಹ್ಯಾಕಾಶಕ್ಕೆ ಪ್ರತಿಫಲಿಸುತ್ತದೆಯಾದ್ದರಿಂದ ಮಂಜುಗಡ್ಡೆ ಕರಗುವುದು ಸ್ವಲ್ಪ ಮಟ್ಟಿಗೆ ನಿಯಂತ್ರಣವಾಗುತ್ತದೆ. ಆದರೆ ಮಂಜುಗಡ್ಡೆ ತೇಲುತ್ತಿರುವ ಕಡುಬಣ್ಣದ ಸಮುದ್ರದ ನೀರು ಸೂರ್ಯನ ಶಾಖವನ್ನು ಹೀರಿಕೊಳ್ಳುವುದರಿಂದ ಸಮುದ್ರದ ನೀರು ಬಿಸಿಯಾಗಿ ಉಳಿದ ಮಂಜುಗಡ್ಡೆಗಳೂ ವೇಗವಾಗಿ ಕರಗುತ್ತವೆ. ಇದರ ನೇರ ಪರಿಣಾಮ ಮಂಜುಗಡ್ಡೆಯನ್ನೇ ನಂಬಿರುವ ಧ್ರುವ ಕರಡಿಗಳು, ವಾಲ್ರುಸ್‌ಗಳು ಮುಂತಾದ ಪ್ರಾಣಿಸಂಕುಲಗಳ ಆವಾಸಸ್ಥಾನ ನಾಶವಾಗುತ್ತಿವೆ. ಸಮುದ್ರದ ನೀರು ಕರಗುತ್ತಿರುವುದು ಜಾಗತಿಕ ಹವಾಮಾನ ಮತ್ತು ಸಮುದ್ರ ಮಟ್ಟ ಏರಿಕೆಯ ಮೇಲೆ ಗಂಭೀರ ಪರಿಣಾಮ ಬೀರುತ್ತಿದೆ.

ಡಾ. ಶಾರದಾ ನಾಗಭೂಷಣ, ಎ.ಪಿ.ಎಸ್. ಕಾಲೇಜು, ಬೆಂಗಳೂರು

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THE UNIVERSE UNDER YOUR TOENAIL

If you look down at your feet at this very moment, you will learn that your toenails just grew about one nanometre. That invisible distance is the frontier of the most powerful field of study in science today. Welcome to the world of nanotechnology, where the smallest is the most powerful.

So, How Small is Nano?

The word "nano" comes from the ancient Greek word for dwarf. In science, it means one-billionth. A nanometer (nm) is one-billionth of a meter ($1nm = 10^{-9}$ m).

So just for comparison, a single strand of human hair is about 100,000 nanometers wide.

Nano Changed All Rules!!

It has been noticed that as soon as a material comes into the nano size, they start to act different. The normal rules of physics do not apply to them and specific set of rules given by quantum mechanics takes over.

Some of the changes that can be seen are:

Color Chameleon

Some materials in nano scale changes color. For example, gold in bulk is yellow in color, however when gold is in nano scale, its color lies between red and purple.

1. Increased Strength

You must have seen Carbon in your pencil and observed that it breaks easily. However, if the same Carbon in nanoscale is rolled up into a tube called Carbon nanotubes, its strength increases 100 times that of steel but six times lighter than steel.

2. Superior Reactivity

Since the surface to volume ratio of nanomaterials is large as compared to bulk, nanomaterials speed up the reactions and acts as catalysts for the reaction.

3. Nanotechnology Hiding at Your House

Can you even imagine that you don't have to wait to see the effect of nanotechnology, it's already near you.

Smartphones

Nanotechnology made possible the small sized phone that you carry around. The nano sized transistors in the phone chip made it possible for the phone to be carried around without being bulky.

Sunscreen

Sunscreen contains Zinc Oxide nanoparticles which are superb at absorbing the sun's harmful UV radiations.

Stain Resistance Clothing

Stain resistance clothing has a tiny layer of nanoparticles called "Nano whiskers" which does not allow stains to remain on clothes.

Medical Applications

Nanomaterials also finds wide applications in medical field as a treatment and diagnosis technique.

Plenty of Room at the Bottom

As famous physicist named Richard Feynman said in his talk in 1959 that **"There is plenty of room at the bottom"** meaning that now mankind should focus on to manipulate individual atoms.

This has come entirely true and now mankind and the science community is shifting the focus to the invisible world beneath out fingertips. Cleaner energy, stronger building, and life saving medicines are some of the frontiers where nanotechnology has shown wonders and still continuing to do so.

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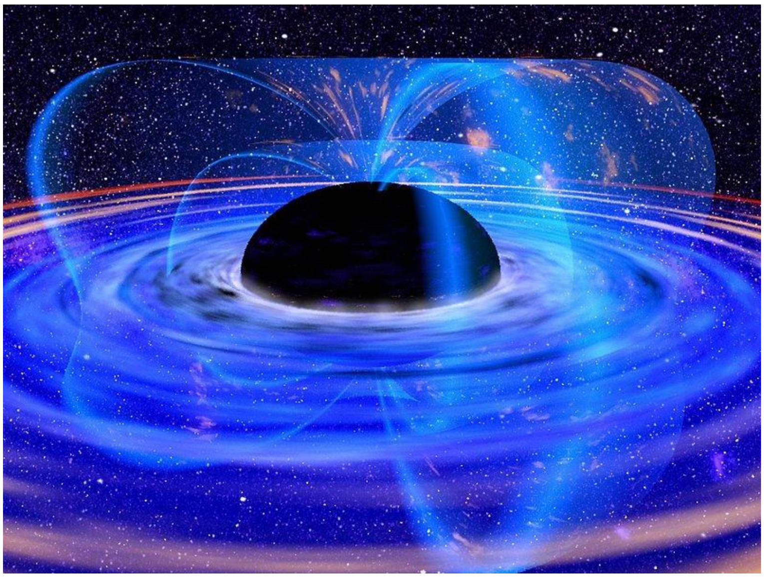
EVERYTHING ABOUT BLACK HOLES



A Black Hole with its magnetic and electric fields

A Brief Introduction to the Physics of Black Holes

I would like to tell each and every one of you, you are in for a long ride if you hope to read the entirety of my paper. Those who have the patience will be rewarded with a healthy dose of knowledge. I am hoping that you are one of the people who will make it to the end despite this paper's volume.

Now, to the main matter of black holes.

Have you ever wondered if other universes exist? Well, astronomers have reason to believe that other universes exist, and what's more, they may even be within our reach within a few centuries. All because of black holes.

You may be asking, **"How is that even possible? Black holes just destroy stuff!"**

To that I say, read the rest of this informative paper and learn more about extraordinary black holes' lifecycles, their effects, along with some cosmic fun facts. Hop along and tour the galaxy to learn more about these amazing black holes!

A Black Hole's Lifecycle
How do black holes form, and what happens to them? How do they progress and gain mass?
To answer these pressing questions, I will educate you about black hole life cycles. Most objects have lifecycles, and black holes are no exception.

Black Hole Classification
Black holes are classified on how much mass they have relative to our Sun, measured in 'Solar Masses'.
There are three classes of black holes observed to-date, stellar black holes and supermassive black holes. Stellar black holes have up to dozens of solar masses, and supermassive black holes have up to 10s of billions of times more mass than our Sun.

The Rarest Class of Black Hole Observed

No black holes start out in the intermediate-class, and this partly explains why intermediate class black holes are very rare.
Intermediate class black holes only form when 2 stellar mass black holes collide, and the most prominent black hole collision that resulted in intermediate class is GW190521.
The GW190521 collision resulted in a black hole with the mass of 142 solar masses.
These collisions result in one of the most energetic interactions in the universe, releasing the equivalent of septendecillions of volts just in a matter of milliseconds in the form of gravitational waves.

Requirements for Black-Hole-Hood

When a star with more than 20 solar masses runs out of the fission fuel and blows out the outer layer the beginning of a black hole is near.

According to NASA,

"if the remaining core contains more than 3 solar masses, then no known force in the entirety of the universe can stop its eventual collapse into a black hole".

Once born, black holes violently steal mass from neighboring stars and even other black holes (only if they have more mass).

The Age of The Galactic Beasts

Black holes are one of the oldest cosmic objects around. They have been around for billions of years and they have existed since the formation of galaxies.

Even though they have been around for so long, they must have been even older if primordial black holes exist.

It is possible that a fourth class of black holes, primordial black holes, which would have very low mass, almost that of something comparable to a planet, but for them to exist, black holes must have existed very early on in the universe's early billions.

The Event Horizon

The reason that black holes have event horizons is because all of the mass has an immense amount of gravity. That gravity then attracts more mass and crushes it all together.

Due to the fact that gravity is inversely proportional with distance squared, the density of the crushed mass makes it so that you are closer to the mass. The increased gravity from the denser object attracts more mass giving more gravity making it get denser, increasing gravity attracting more mass increasing gravity getting more dense until it becomes so dense that the escape velocity is greater than the c and the entire thing collapses into a singularity and forms a black hole.

Hawking Radiation and The Gradual Destruction of A Black Hole

These monstrous munchers evaporate their mass away slowly by a process called hawking radiation.

This is the only known way to "destroy" or "get rid of" black holes.

We have never seen proof of black holes evaporating.

Now that you are in the know about how these cosmic consumers are formed and how they progress through their life, and inevitably die, you may wonder or worry about their impact on the real world.

Black Hole's Effects On Matter

Black holes' effects are no laughing matter (pun intended). They can rip planets to pieces, shred stars, and merge together in terrifying collisions known as black hole mergers, which release so much energy, even from lightyears away, we can detect them.

Gravity and Gravity Related Black Hole Shennanigans

The gravity from black holes exert tidal forces on the matter orbiting the black holes, causing it to speed and heat up, release destructive radio, xray, and gamma ray photons, and sometimes be flung out of orbit, sent flying into the cosmic nothingness.

These orbit flingings cause large amounts of particles and photons to come out of the ends of the black hole, producing huge jets of superheated plasma that spans lightyears and shines brighter than entire galaxies combined.

Fantastic (Beasts) Black Holes and (Where) How to Find Them

Black holes emit gravitational waves travelling at c, and these gravitational waves can be detected. The most famous black hole gravitational wave detector is LIGO.

Albert Einstein predicted that black holes will emit gravitational waves (along with predicting their existence), and made a few ideas on how to detect black holes.

LIGO detects black holes by observing their effects on photons in a LASER, as the gravity will cause them to slightly misalign, causing the LASER to bend slightly. This slight bend makes the observer not pick up on all of the photons, effectively informing you if there are gravitational waves in the area (accounting for the Earth's gravitational effects).

These jets of plasma and photons along with the gravitational waves can be detected from Earth, even without black holes in our immediate vicinity because the gravity of a black hole warps spacetime a butt-ton.

For black holes, they have so much gravity that their escape velocity is higher than the c, therefore nothing can escape once it gets "too close".

"Too close" limits for black holes are known as event horizons, because they are the area around a black hole where the escape velocity is greater than c, effectively dictating the area of space that we cannot ever observe.

The "too close" limit for a non-rotating black hole is given by the Swarzchild Radius equation which is $\mathbf{rs = 2GMc^{-2}}$.

The "too close" limit for a rotating black hole is given by the Swarzchild Radius equation $\mathbf{rs = GMc^{-2} + ((GMc^2)^2 - J^2M^{-2}c^{-2})^{1/2}}$.

Non-Annihilation

Black holes cannot annihilate with antimatter like normal matter-made substances can, as anything that comes into the event horizon only adds to its mass, an effect unique to objects which escape velocity is greater than the c.

Quantum Mechanics says that when you combine an antimatter black hole and a black hole of the same mass, there should be a black hole with the double the mass of the original one even though matter-antimatter annihilation happens within, it is only within the event horizon, and the energy released cannot escape it.

Due to mass-energy conservation and the fact that mass, energy and speed are the only factors that trigger gravitation, even if all of the matter and antimatter is gone, the photons released in the process still contribute to the gravitational effects, and the effects of all the photons combined must be equivalent to the effect of the mass of both black holes, as antimatter still has positive mass (as far as testable effects go (see Penning Traps, CERN, Antigravity theories, CPT violations, Quantum Field Theory, Quantum Mechanics)).

A small minority of physicists think that there is a possibility that black holes can delete the information of any particle that enters it other than mass, charge, and angular momentum, therefore "forgetting" if a particle which enters is matter or antimatter, or if it can annihilate with the particles in the black hole.

"Warping the Fabric of Spacetime": A Day in The Life of A Black Hole

Black holes also bend spacetime so much that you can see the back of the black hole from the front due to the gravitational lensing.

The gravitational lensing effect happens when a photon comes into a gravitational field, where the influence of gravity ever so slightly changes its trajectory.

Now that you know how these dark destroyers work and how they consume mass, let us dive into other mechanisms exceptional black holes use.

Fabric-of-Reality-Warping Fun Facts

You may still have questions about how black holes transport people to other universes or break the fabric of spacetime.

Well fear not, because I can answer all of your questions, (as you may have already noticed).

To Answer the Question of Spaghetti

You may have heard a term called spaghettification.

Spaghettification is an informal term that refers to the stretching and distortion of matter, referring to the stretching of matter into a spaghetti-like shape due to the gravitational effects of a black hole.

Sphaghettification is only noticeable when you are close to the black hole's event horizon.

If you were close enough to the black hole, you would be stretched apart by the tidal forces and your feet would plummet toward the black hole while the rest of your body would be much less affected by the gravity.

Other Universes and the Einstein-Rosen Bridge

You may have also heard that when someone enters a black hole, they are transported to another universe, spat out by a white hole, the theoretical opposite of a black hole (not to suggest that they combine to be nothing or could annihilate), and if they enter the singularity that they will go to another "antiverse" where every property of everything in the original universe is reversed, along with mass.

This is actually true (according to the theory of special and general relativity) though it is impossible to test, and the only way to confirm is if we find a white hole (even though these white holes would likely be spitting radiation just welcoming us to discover it (then again when has Einstein been wrong, we didn't believe him about black holes and here I am writing a paper about it)).

The Common Misconception

Unlike black holes, white holes do not have to be white. Black holes are black because they trap in light, but white holes do not have to be white because they expel anything that comes through the other side, and photons from the other side can contain any wavelength and/or amplitude, including not only white, but red, yellow, green, blue, or any other color.

The Density Difference

You may have heard of another cosmic consumer, the neutron star, and you may have heard that a teaspoon of their matter would be heavier than every single thing on the surface of the Earth combined, weighing a whopping 4 billion tons.

This is true, as neutron stars are incredibly dense.

You may be asking, how do black holes compare?

In density, neutron stars decimate black holes with absolutely no competition. Most black holes have a density less than water's, meaning that if you could find a pool big enough (and somehow made it immune to the gravitational effects of the black hole) it would float.

Pretty neat right?

In what black holes lack in density, they make up for in mass. Black holes are significantly more massive and gravitationally dominant.

In fact, black holes are the most massive singular objects in the universe, with TON 618, the most massive one, having 66 billion solar masses. The entire solar system could fit into it snuggly.
For comparison the supermassive black hole in our galaxy, Sagittarius A*, is 67,000 times smaller.

References

1. Gohd, Chelsea. 2023. *What Happens When Something Gets "Too Close" to a Black Hole? - NASA Science*, Science.nasa.gov (NASA).
2. NASA. 2024. *Hubble Black Holes - NASA Science*, Nasa.gov.
3. Reddy, Francis. 2020. *What Are Black Holes?*, NASA.
4. *The Einstein-Rosen Bridge*. 2015. I4is.org.

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Family Joke
Child: Dad, what's inside a black hole?
Dad: If scientists knew that, they'd all have Nobel Prizes!

Physics Exam
Teacher: Define a black hole.
Student: It's the place where my marks disappear after every physics exam!

AI Meets Black Hole
AI: I can answer almost every question.
Physicist: Then tell me what happens inside a black hole.
AI: ...Let's change the topic

Gravity Has a Sense of Humour
Student: "Sir, what is a black hole?"
Teacher: "It's the only place where your homework has a chance of never being found!

The Astronomer
Friend: Why do astronomers love black holes?
Astronomer: Because they always **draw everyone in!**

CONTRIBUTIONS OF KERALA MATHEMATICIANS TO ASTRONOMY

The Kerala School of Mathematics and Astronomy, which flourished between the fourteenth and seventeenth centuries CE in present-day Kerala, represents one of the most significant traditions in the history of Indian science. Founded by Mādhava of Saṅgamagrāma (c. 1340–1425 CE), the school made remarkable advances in mathematical astronomy (*jyotiḥśāstra*) by combining sophisticated mathematical techniques with accurate astronomical observations. Its scholars developed innovative methods for planetary calculations, trigonometry, infinite series, and computational astronomy, many of which anticipated ideas later associated with calculus.

The principal aim of the Kerala School was to improve the accuracy of astronomical predictions. Earlier Indian astronomers such as Āryabhaṭa, Brahmagupta, Bhāskara II, and the authors of the **Sūrya Siddhānta** had established mathematical procedures for determining planetary positions, eclipses and calendars. Kerala mathematicians refined these methods by introducing more precise computational techniques and correcting accumulated errors through systematic observation.

Mādhava of Saṅgamagrāma – The Founder

The founder of the school, Mādhava of Saṅgamagrāma, is regarded as one of the greatest mathematician-astronomers in Indian history. Although none of his original works survive in complete form, his discoveries are preserved in later texts by his successors.

Mādhava developed infinite series expansions for trigonometric functions such as sine, cosine and arctangent. He also derived the celebrated infinite series for π,

$$\frac{\pi}{4}=1-\frac{1}{3}+\frac{1}{5}-\frac{1}{7}+\frac{1}{9}-\frac{1}{11}+\cdots$$

along with correction terms that significantly accelerated convergence, enabling highly accurate approximations of π. These results were applied to astronomical calculations involving planetary longitudes and eclipse computations.

One of Mādhava's major contributions was the improvement of trigonometric tables. Earlier Indian astronomers employed sine tables based on finite intervals. Mādhava introduced refined interpolation methods and more accurate sine values, greatly enhancing the precision of astronomical computations. These improvements reduced observational errors and made planetary predictions more reliable.

Parameśvara (c. 1360–1455 CE)

Among Mādhava's distinguished successors was Parameśvara (c. 1360–1455 CE), an eminent astronomer known for his careful observational work. Over several decades, he recorded planetary positions and eclipses, comparing observed values with theoretical predictions. His work demonstrated the importance of empirical verification in astronomy.

Parameśvara also introduced the **dṛggaṇita** ("observational astronomy") approach, emphasizing calculations based on actual observations rather than relying solely on traditional astronomical constants. His treatises, including the **Dṛggaṇita** and commentaries on earlier astronomical works, contributed significantly to improving computational accuracy.

One of Parameśvara's greatest achievements was his extensive programme of astronomical observations. Historical records indicate that he observed solar and lunar eclipses, planetary conjunctions, and other celestial phenomena continuously for nearly 55 years. These observations were carefully compared with the predictions of existing astronomical models, enabling him to identify discrepancies and refine computational methods. This long series of observations represents one of the earliest sustained observational programmes in medieval Indian astronomy.

Parameśvara is particularly associated with the **Dṛggaṇita** ("observational computation") tradition. The term **dṛk** means "observation" or "direct perception," and **gaṇita** means "calculation." Unlike earlier astronomical texts that relied primarily on traditional constants derived from the **Sūrya Siddhānta** or Āryabhaṭa's works, the Dṛggaṇita approach emphasized adjusting astronomical parameters according to actual observations. This significantly improved the accuracy of predictions for planetary positions, eclipses, and conjunctions.

Parameśvara also composed several commentaries on classical Sanskrit astronomical texts. His **Bhāṭadīpikā**, a commentary on Āryabhaṭa's **Āryabhaṭīya**, explains difficult mathematical procedures, planetary computations, eclipse calculations, and trigonometric methods with remarkable clarity. Similarly, his commentary on the **Laghubhāskarīya** of Bhāskara I helped preserve and interpret earlier astronomical knowledge while introducing refinements based on contemporary observations.

Another notable contribution was his commentary on the **Goladīpikā**, dealing with spherical astronomy. In this work, Parameśvara discussed celestial coordinates, the apparent motion of heavenly bodies, rising and setting phenomena, and methods for solving astronomical problems involving the celestial sphere. These studies were essential for understanding planetary motion and for preparing accurate astronomical calendars.

Parameśvara made important improvements in eclipse computation. By refining lunar and solar parameters and employing more accurate trigonometric values inherited from Mādhava's work, he obtained better predictions of eclipse timings, duration, and magnitude. His computational methods significantly reduced errors found in earlier astronomical tables and enhanced the reliability of traditional Indian astronomical calculations.

His mathematical contributions were equally important. He employed interpolation techniques for improving trigonometric tables and utilized more accurate sine values in astronomical computations. These methods allowed astronomers to calculate planetary positions with greater precision and formed an essential component of the Kerala School's computational astronomy.

Nīlakaṇṭha Somayājī (1444–1544 CE)

Another leading scholar, Nīlakaṇṭha Somayājī (1444–1544 CE), was one of the greatest astronomer-mathematicians of the Kerala School of Astronomy and Mathematics. A disciple in the scholarly tradition of Parameshwara and Damodara, he combined careful astronomical observations with rigorous mathematical methods. His works mark the culmination of the Kerala School's achievements and significantly advanced Indian astronomy.

Nīlakaṇṭha composed the celebrated **Tantrasaṅgraha**, one of the finest works of medieval Indian astronomy. In this text, he presented a revised planetary model that explained the motions of the inner planets (Mercury and Venus) more accurately than earlier geocentric systems. His model represented an important refinement of traditional Indian planetary theory and demonstrated a deep understanding of celestial mechanics within the geocentric framework.

Nīlakaṇṭha's **Tantrasaṅgraha** also contained systematic methods for calculating planetary positions, conjunctions, eclipses, and lunar phenomena. His commentary, **Āryabhaṭīyabhāṣya**, further explained astronomical theories and clarified several computational procedures inherited from Āryabhaṭa. These works remained influential for centuries in southern India.

Nilakantha made several important contributions to mathematics in support of astronomical computation. He employed highly accurate sine tables and trigonometric techniques inherited from Madhava and refined their application in astronomy. His works make use of infinite series expansions for trigonometric functions, reflecting the advanced mathematical tradition of the Kerala School. These methods anticipated developments in calculus by several centuries.

Nilakantha's greatest contribution was the development of an improved planetary model. His astronomical achievements include:

- Proposing a geo-heliocentric model in which Mercury and Venus revolve around the Sun while the Sun revolves around the Earth.
- Improving the geometrical explanation of the motions of Mars, Jupiter, and Saturn.
- Refining eclipse calculations through better mathematical techniques.
- Applying advanced trigonometry to astronomical computation.
- Emphasizing observational verification of theoretical models.
- Improving the accuracy of planetary tables used for astronomical prediction.

His planetary system was among the most sophisticated developed anywhere before the work of Johannes Kepler and represented the highest achievement of medieval Indian astronomy.
Nilakantha Somayaji occupies a central position in the history of Indian science. Building upon the observational methods established by Parameśvara and the mathematical innovations of Madhava, he synthesized these traditions into a comprehensive astronomical system. His works demonstrate an exceptional combination of theoretical reasoning, mathematical precision, and empirical observation.

Jyeṣṭhadeva and Other Scholars

Jyeṣṭhadeva (c. 1500–1575 CE) made a unique contribution by recording the mathematical reasoning behind many of Mādhava's discoveries. His Malayalam work **Yuktibhāṣā** is one of the earliest known texts to present detailed mathematical proofs and derivations in a regional Indian language. It explains infinite series, trigonometric identities, methods of approximation, and astronomical computations step by step. The text illustrates how mathematical reasoning supported practical astronomical calculations and provides invaluable insight into the intellectual methods of the Kerala School.

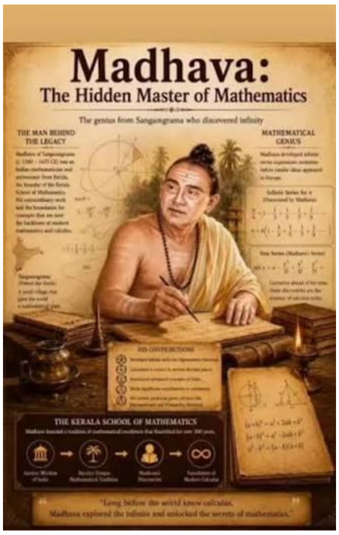
Other scholars, including Śaṅkara Vāriyar, Acyuta Piṣāraṭi, Nārāyaṇa Bhaṭṭathiri, and Mēlpathūr Nārāyaṇa Bhaṭṭatiri, continued the Kerala tradition by writing commentaries, refining computational techniques, and preparing improved astronomical manuals. Acyuta Piṣāraṭi, in particular, produced works on eclipse computation and planetary motion while emphasizing observational accuracy. Their writings ensured that the mathematical and astronomical achievements of the Kerala School were transmitted to later generations.

Distinctive Features and Legacy

A distinctive feature of the Kerala School was its extensive use of advanced mathematics in astronomy. The scholars employed infinite series, interpolation techniques, iterative numerical methods, and sophisticated trigonometry to solve practical astronomical problems. Their mathematical innovations were motivated by the need to improve the precision of astronomical calculations rather than by abstract mathematical inquiry alone.

The Kerala mathematicians also contributed significantly to calendar making (*pañcāṅga* preparation). Their improved methods enabled more accurate prediction of eclipses, planetary conjunctions, solstices, equinoxes, and other astronomical events. These calculations were important for determining religious festivals, agricultural activities, and civil timekeeping.

Modern historians of mathematics recognize the Kerala School as one of the most creative scientific traditions of medieval India. Scholars such as K. V. Sarma, C. T. Rajagopal, M. S. Narasimhan, K. Ramasubramanian, George Gheverghese Joseph, and Kim Plofker have highlighted the originality and sophistication of its mathematical astronomy. Although the precise historical relationship between the Kerala School and later European developments remains a subject of scholarly debate, there is broad agreement that the Kerala mathematicians independently developed remarkable techniques in infinite series, trigonometry, and computational astronomy.



Conclusion

In conclusion, the Kerala School of Mathematics and Astronomy occupies a distinguished place in the history of science. Through the pioneering work of Mādhava, Parameśvara, Nīlakaṇṭha Somayājī, Jyeṣṭhadeva, and their successors, the school transformed Indian mathematical astronomy by introducing innovative computational methods, refining planetary models, improving trigonometric calculations, and emphasizing observational accuracy. Their achievements constitute one of the greatest scientific traditions of pre-modern India and continue to attract the attention of historians of mathematics and astronomy.

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When Europe Was Still Debating…

More than **500 years ago**, in a quiet village in Kerala, scholar **Nilakantha Somayaji (1444–1544)** spent countless nights observing the sky.

With no telescope, no computer, and no modern instruments, he relied only on careful observation, mathematics, and extraordinary patience.

One evening, while studying the movements of the planets, he realized that the existing models did not explain their paths accurately. Through years of calculations, he proposed a more refined model of planetary motion and developed an improved infinite series for calculating π, centuries ahead of similar developments in Europe.

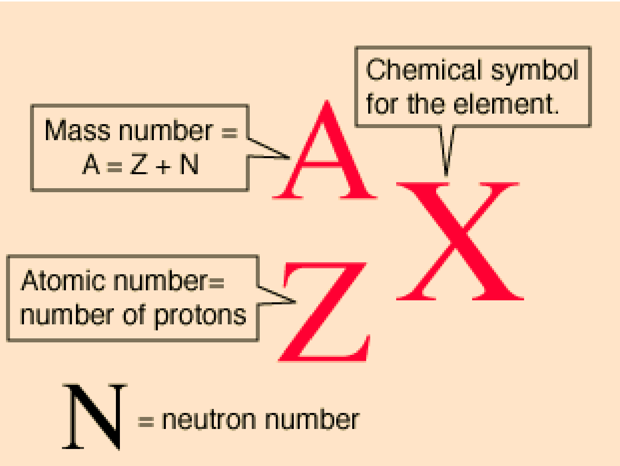
Today, historians recognize the **Kerala School of Mathematics and Astronomy** as one of the world's remarkable centres of scientific thought.

"Great discoveries are born not only in grand laboratories, but also in quiet minds that dare to observe, calculate, and question

NUCLEAR PROPERTIES

Nuclear Notation

Standard nuclear notation shows the chemical symbol, the mass number and the atomic number of the isotope.



The element is determined by the atomic number 6. Carbon-12 is the common isotope, with carbon-13 as another stable isotope which makes up about 1%. Carbon-14 is radioactive and the basis for carbon dating. The mass of an element that is numerically equal to the atomic mass **A** in grams is called a mole and will contain Avogadro's number $\mathbf{N_a}$ of nuclei. If the density **ρ** of the material is known, then the number of nuclei per unit volume **n** can be calculated from:

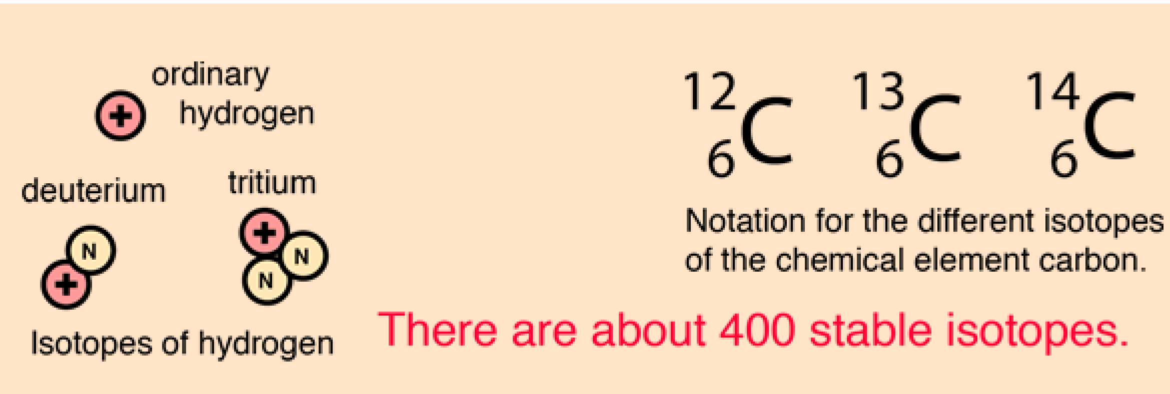
$\mathbf{n = \rho N_a/A}$

This is useful in calculating the cross section for nuclear scattering.

Example: the isotopes of carbon $_6C^{12}$, $_6C^{13}$, $_6C^{14}$

Isotopes

The different isotopes of a given element have the same atomic number but different mass numbers since they have different numbers of neutrons. The chemical properties of the different isotopes of an element are identical, but they will often have great differences in nuclear stability. For stable isotopes of light elements, the number of neutrons will be almost equal to the number of protons, but a growing neutron excess is characteristic of stable heavy elements.

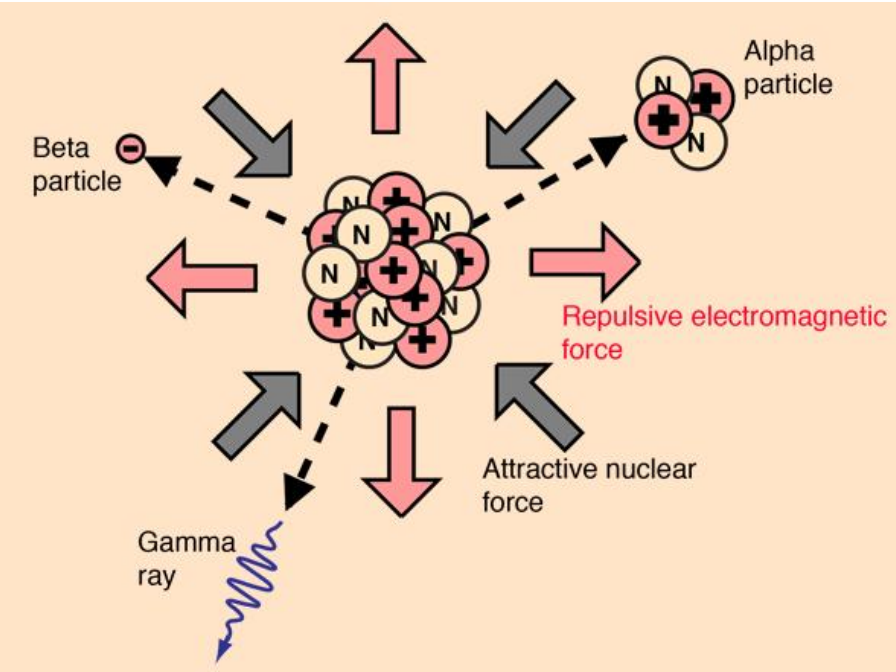


It is significant to note that the three isotopes of hydrogen change in mass by a factor of three, but their chemical properties are virtually identical. A tiny difference in the spectral frequencies of hydrogen and deuterium comes from an essentially mechanical source, the slight change in the "reduced mass" associated with the orbiting electron.

But for practical purposes the chemical behaviour of the isotopes of any element are identical. The dominant contributor to the interactions between atoms and their environment is the electromagnetic force. It should not be surprising that an extra neutron or two in the nucleus has almost no effect on that interaction with the world.

Examination of a scale model of the atom makes it evident that the nucleus is extremely tiny compared to the size of the atom. The nuclear radius of carbon-12 is **2.7×10^{-15} m** while the size of the atom from the periodic table is about **0.9×10^{-10} m**, about **33,000 times larger!**

Nuclear Forces



Within the incredibly small nuclear size, the two strongest forces, Nuclear and Electromagnetic forces in nature are pitted against each other. When the balance is broken, the resultant radioactivity yields particles of enormous energy.

The electron in a hydrogen atom is attracted to the proton nucleus with a force so strong that gravity and all other forces are negligible by comparison. But two protons touching each other would feel a repulsive force over **100 million times stronger!!**

So how can such protons stay in such close proximity?

This may give you some feeling for the enormity of the nuclear strong force which holds the nuclei together.

Nuclear Size

The size of the nucleus compared to the size of the atom in which it resides is so small that it has invited a number of interesting comparisons. For example, the space inside an atom can be compared to the space in the solar system in a scale model.

Scaling the gold nucleus suggests that the atomic radius is some **18,000 times** the size of the nucleus. This great disparity in size was first discovered by Rutherford scattering of alpha particles off a thin gold foil.

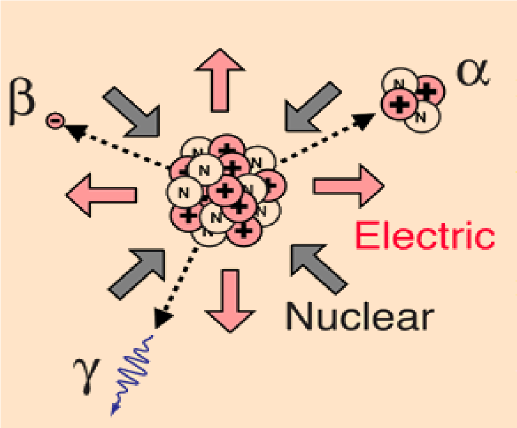
The extremity of this space comparison is highlighted by the fact that for an atom with equal numbers of neutrons and protons, the nucleus comprises about **99.97%** of the mass of the atom!

Experimental evidence suggests that nuclear matter is almost of uniform density, so that the size of a nucleus can be estimated from its mass number.

Radioactivity refers to the particles which are emitted from nuclei as a result of nuclear instability. Because the nucleus experiences the intense conflict between the two strongest forces in nature, it should not be surprising that there are many nuclear isotopes which are unstable and emit some kind of radiation.

The most common types of radiation are called **alpha, beta, and gamma radiation**, but there are several other varieties of radioactive decay.

Radioactivity



Radioactive decay rates are normally stated in terms of their half-lives, and the half-life of a given nuclear species is related to its radiation risk.

The different types of radioactivity lead to different decay paths which transmute the nuclei into other chemical elements. Examining the amounts of the decay products makes possible radioactive dating.

Radiation from nuclear sources is distributed equally in all directions, obeying the inverse square law.

Alpha, Beta and Gamma Radioactivity

Alpha Radiation

Alpha particle is a nucleus of the element helium which consists of two protons and two neutrons. Because of its very large mass (more than **7000 times** the mass of the beta particle) and its charge, it has a very short range.

It is not suitable for radiation therapy since its range is less than a tenth of a millimetre inside the body. Its main radiation hazard comes when it is ingested into the body; it has great destructive power within its short range. In contact with fast-growing membranes and living cells, it is positioned for maximum damage.

Alpha particle emission is modelled as a barrier penetration process. The alpha particle is the nucleus of the helium atom and is the nucleus of highest stability.

Beta Radiation

Beta particles are just electrons from the nucleus, the term **"beta particle"** being an historical term used in the early description of radioactivity.

The high energy electrons have greater range of penetration than alpha particles, but still much less than gamma rays. The radiation hazard from betas is greatest if they are ingested.

Beta emission is accompanied by the emission of an electron antineutrino which shares the momentum and energy of the decay. The emission of the electron's antiparticle, the positron, is also called beta decay.

Beta decay can be seen as the decay of one of the neutrons to a proton via the weak interaction. The use of a weak interaction Feynman diagram can clarify the process.

Gamma Radiation

Gamma radioactivity is composed of electromagnetic rays. It is distinguished from x-rays only by the fact that it comes from the nucleus.

Most gamma rays are somewhat higher in energy than x-rays and therefore are very penetrating. Gamma radiation is the most useful type of radiation for medical purposes, but at the same time it is the most dangerous because of its ability to penetrate large thicknesses of material.

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LIGHT SLOWED, STOPPED AND TRANSPORTED AS MATTER

(Lene Hau's Landmark Experiments in Quantum Optics (1999–2007))

"All these fifty years of conscious brooding have brought me no closer to the answer to the question: What are light quanta?"

— **Albert Einstein**

Introduction

At the beginning of the 21st century, experiments by Lene Hau and her colleagues at Harvard University provided a remarkable answer. They showed that light is not only something that travels through space at an enormous speed; under carefully controlled quantum conditions, it can be slowed to the speed of a bicycle, brought to a complete stop, stored in matter, transported as matter, and later recreated as light.

These experiments represented one of the most elegant demonstrations of the intimate relationship between light and matter in modern physics.

The speed of light in vacuum, **299,792 km/s**, is one of the fundamental constants in physics and represents the ultimate speed limit in the universe according to Einstein's theory of relativity. Light travels from the Earth to the Moon and back in only about **2.5 seconds**. Such an enormous speed is difficult for human beings to imagine.

However, when light enters a transparent material medium, its speed is reduced because of interactions with the atoms of the material. In water, light travels at about **225,000 km/s**, in glass about **200,000 km/s**, and in diamond about **125,000 km/s**. Although these reductions are significant, they are still small compared with the speed of light in vacuum.

The idea that light could slow down to a human walking pace—or even stop completely—appeared impossible, was possible in science fictions. Yet, in 1999, Lene Hau and her team achieved exactly this using an unusual state of matter called a **Bose–Einstein Condensate (BEC)** and quantum processes—**Electromagnetically Induced Transparency (EIT), Two-photon Raman process and Inverse Raman process**.

The Bose–Einstein Condensate: A Quantum Medium for Controlling Light

The medium chosen by Lene Hau was not an ordinary material but a **Bose–Einstein Condensate (BEC)** of sodium atoms cooled to such temperatures as low as a few billionths of a degree above absolute zero.

A BEC is formed when atoms belonging to a class called bosons are cooled to extremely low temperatures. At ordinary temperatures, atoms move randomly and behave as individual particles. However, when the temperature is reduced below a critical value, a large number of atoms collapse into the lowest energy state.

The atoms lose their individual identities and begin to behave collectively as a single quantum system—**A Super atom**. In this state, the condensate is described by a single macroscopic quantum wave function.

The importance of a BEC in Lene Hau's experiments is, of the use of the property that atoms in the condensate behave in a coordinated manner. Their common quantum phase provides an exceptionally clean environment where interactions between light and matter can be controlled with extraordinary precision.

Electromagnetically Induced Transparency (EIT)

A Bose–Einstein condensate alone cannot slow light. The crucial ingredient is a quantum phenomenon known as **Electromagnetically Induced Transparency (EIT).**

It is a quantum interference phenomenon where a medium otherwise opaque to certain light (probe pulse) becomes transparent in the presence of a second, strong laser (control).

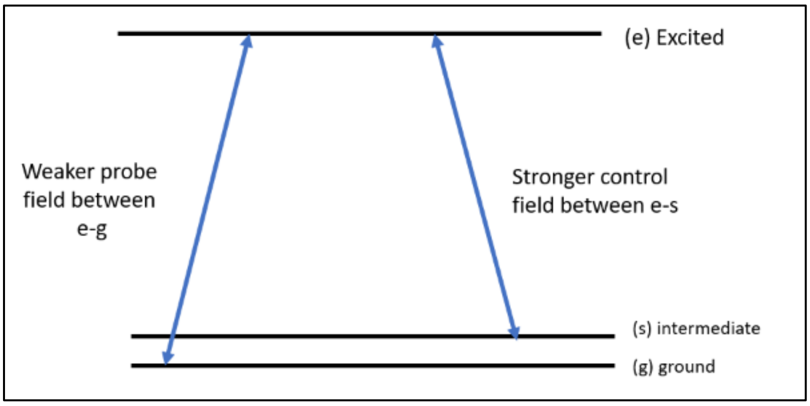


Fig 1: sodium atom – 3 Energy

In Lene Hau's experiment, each sodium atom of the medium behaved as a three-level system with two closely spaced ground states, **g** and **s**, and one excited state, **e**.

A weak probe pulse—the light to be slowed—was tuned to the **g** → **e** transition, while a strong control laser was tuned to the **s** → **e** transition.

When only the probe beam is present

- Atoms absorb the probe photons.
- They are excited to state **e**.
- Later they emit photons randomly.
- The probe pulse is absorbed and the condensate is opaque.

When only the control laser is present

- Virtually nothing happens because almost no atoms initially occupy states.
- The control laser passes through.

When both laser fields are applied simultaneously

The two optical pathways leading to the excited state interfere destructively, so the excited state is almost never populated. The atoms transition from **g** to **s** without ever populating **e**.

As a result, absorption is suppressed and the probe pulse passes through the condensate with negligible loss. The medium, previously opaque, becomes transparent.

EIT opens a narrow width of frequency for the transmission of the probe light. This remarkable phenomenon is known as **Electromagnetically Induced Transparency (EIT).**

Why Does EIT Slow Light?

Making the condensate transparent is only part of the story.

EIT creates an extremely narrow window of transparency frequency range (**dν**), over which the refractive index changes (**dn**) very rapidly with frequency.

This rapid variation of **n** with **ν**, (**dn/dν**) is called **steep dispersion**.

The group velocity of a light pulse is known to be inversely proportional to the dispersion,

$V_g \propto 1/(dn/d\nu)$

The group velocity decreases as the dispersion become steeper.

One of the most beautiful aspects of EIT is that the strength of the control laser determines the width of this frequency window (**dν**) and thereby the steepness of the dispersion.

In a sense the group velocity of the probe light is controlled by the strength of the controlled laser.

Lene Hau and her team were able to decrease the strength of the control laser and obtain group velocity around **17 m/s**.

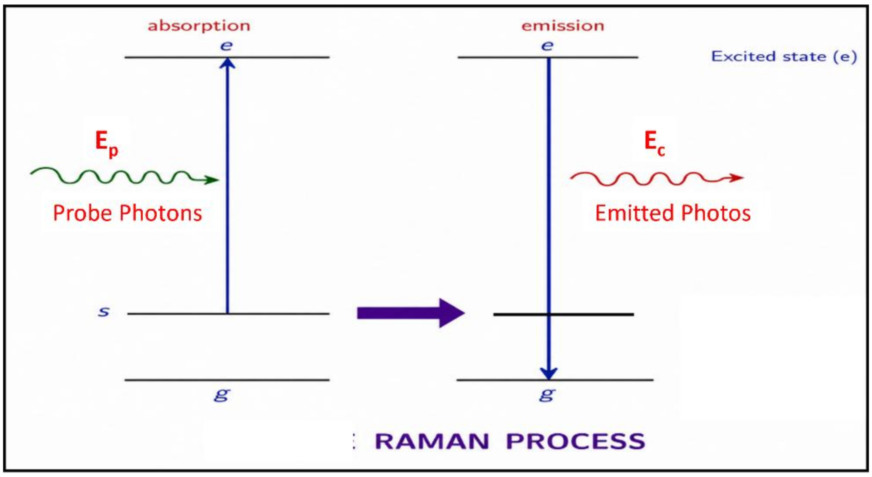
What Actually Happens to the Light While It Is Travelling So Slowly?

The answer lies in two quantum processes:

- **Two-photon Raman process** that generates a spin wave by converting a part of probe light into spin wave.
- **Inverse Raman Process** that converts atomic excitations (spin wave) into the light part that was absorbed earlier.

In Raman process the sodium atom initially in the ground state **g**, interacts simultaneously with the weak probe field and the strong control field. Instead of remaining in the excited state **e**, the atom undergoes a coherent transition to the second ground state while a photon is transferred to the control field.

Because of quantum interference, the excited state is never significantly populated.



The net result is that part of the probe field is coherently converted into an atomic excitation.

At the same time the quantum information—the phase, amplitude, pulse shape and polarization carried by the probe pulse—are transferred to the atomic medium.

The energy balance for the process is:

Energy of probe photon = Energy of control photon + Energy stored in the g–s transition $E_p = E_c + (E_s - E_g)$

In the inverse Raman process, an atom in state **s** interacts with the control field and returns coherently to the ground state **g**, regenerating a probe photon while again avoiding significant population of the excited state **e**.

Together, the Raman and inverse Raman processes provide a reversible mechanism for converting part of the probe light into atomic excitations and reconverting those excitations back into light. These complementary processes continuously exchange energy and quantum information between light and matter without destroying the coherence of the pulse.

What is a Spin Wave?

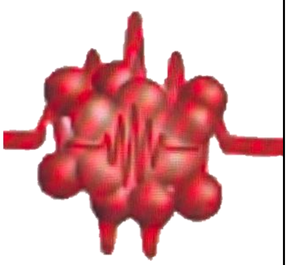
The atomic excitation created during the Raman process is not confined to a single atom. Instead, it is shared coherently by millions of atoms throughout the condensate, forming a collective excitation known as a **spin wave**.

It is this collective excitation that stores all the quantum information carried by the probe pulse.

The Dark-State Polariton

Inside the condensate, the probe pulse exists partly as probe light field and partly as atomic excitations (spin wave). It no longer exists as pure light.

DSP



Mixture of probe light and atomic excitations

This hybrid quasiparticle consisting of two inseparable components—the electromagnetic field of the probe pulse and the collective atomic spin wave—is called **Dark-State Polariton (DSP).**

It is termed **"dark"** because quantum interference prevents significant population of the excited state **e**, thereby eliminating absorption.

The dark-state polariton may be pictured as a travelling conversion zone between light and matter.

- At its leading edge, the Raman process continuously converts part of the probe field into collective atomic spin-wave excitations.
- At its trailing edge, the inverse Raman process converts those atomic excitations back into the probe field.

Thus, as the dark-state polariton propagates through the BEC state, light is continuously transformed into matter-like excitations at its front while matter-like excitations are continuously transformed back into light at its rear.

Experimental Studies

The pulse advances because its energy and quantum information are repeatedly handed from the electromagnetic field to the collective atomic excitation and back again. The individual photons themselves are never slowed between interactions—they always travel locally at the speed of light. The remarkably small group velocity arises because the information carried by the pulse spends part of its journey stored temporarily in the atomic spin wave.

The dark-state polariton is therefore the central player in all of Lene Hau's celebrated experiments on slowing, stopping and storing light.

1. The 1999 Experiment: Light Slowed

In 1999, Lene Hau and her team performed the experiment that first demonstrated this extraordinary control over light. A cigar-shaped Bose–Einstein condensate of sodium atoms was prepared inside an ultra-high vacuum chamber and maintained at a temperature only about 50 nanokelvin above absolute zero. A strong control laser illuminated the condensate.

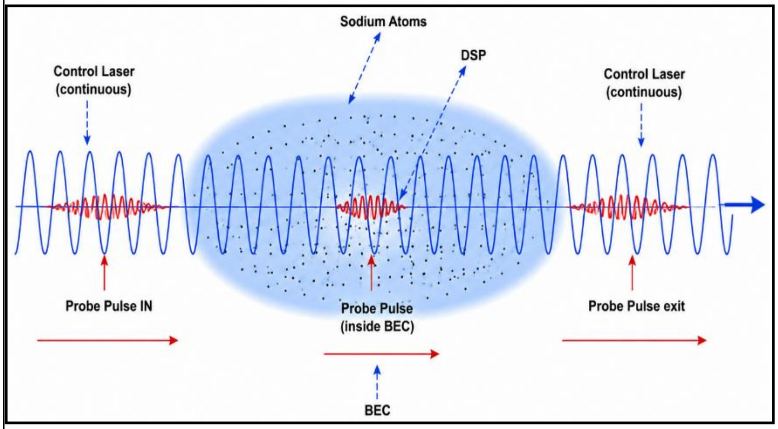


Fig 4: probe pulse slowed in BEC of sodium

A weak probe pulse was then sent into the cloud. The probe pulse on entering the condensate got dramatically slowed and crawled through as a quasi-particle at a speed of about 17 m/s. Finally, when it exits, it travelled again as a light pulse with its normal speed. A pulse that extended over several kilometres in free space was squeezed into a tiny speck of about 0.03 mm inside the condensate.

As soon as the probe pulse entered the condensate, it no longer propagated as an ordinary light pulse. Instead, under the conditions of electromagnetically induced transparency, on interaction with the condensate atoms it is transformed into a DSP—a hybrid quasiparticle consisting of the probe electromagnetic field and a coherent collective spin excitation of the atoms. The polariton travels through the condensate with a group velocity of only about 17 m/s, more than seven orders of magnitude slower than the speed of light in vacuum.

Because the front of the pulse slowed almost immediately while the rear of the pulse was still travelling through free space at its normal speed, the rear rapidly caught up with the front. Consequently, a pulse that would have stretched over several kilometres in free space was compressed into such astonishing length inside the condensate.

As the dark-state polariton moved through the BEC, part of the probe field coherently converted into collective atomic spin excitations through the Raman process, while at the trailing edge the inverse Raman process reconverted these excitations into the probe light field. The polariton therefore propagated as a constantly evolving mixture of light and atomic spin wave rather than as either one alone. Remember that, while the pulse is propagating, the atoms are stationary and the pulse simply moves through.

When the polariton reached the far end of the condensate, its atomic component was completely converted back into light. The probe pulse emerged from the condensate as an ordinary light pulse, once again travelling at the speed of light in free space (299,792 km/s). Remarkably, the regenerated pulse was virtually an exact replica of the original, faithfully preserving its shape, phase and quantum information.

2. The 2001 Experiment: Light Stopped, Stored and Retrieved

The 1999 experiment demonstrated that light could be slowed to an extraordinary degree. But it immediately raised a deeper question:

If the dark-state polariton can be slowed by reducing the control laser intensity, what would happen if the control laser were to be completely switched off while the polariton was still inside the condensate? Would the light come to a complete stop?

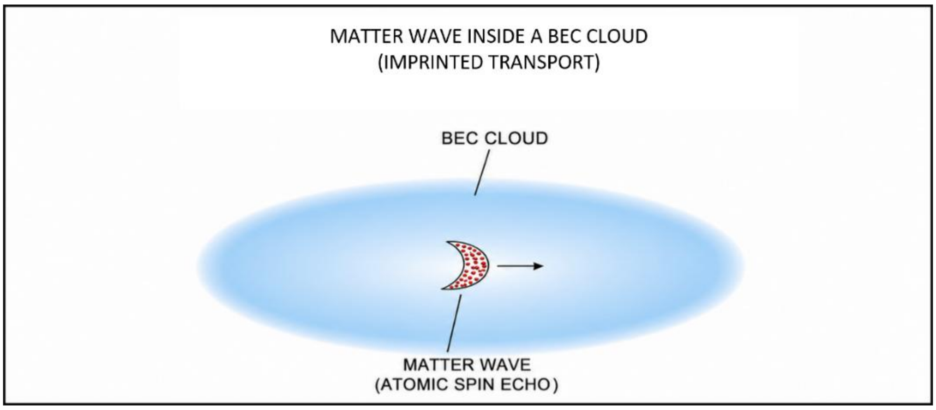


Fig 5: Probe light pulse stored as atomic spin-wave

In 2001, Lene Hau and her colleagues answered this question with another landmark experiment. They succeeded in stopping a light pulse, storing its information inside the atoms of a Bose–Einstein condensate, and later retrieving it as a light pulse again.

This experiment is often described as "stopping light." However, an important clarification is necessary. The photons themselves were not trapped inside the condensate like particles inside a box. The electromagnetic field of the light pulse disappeared completely. What remained was the quantum information carried by the light, stored as a collective atomic excitation.

The light was not imprisoned—it was completely converted into atomic spin wave.

How Was it done?

The experiment began in exactly the same way as the slow-light experiment. A probe pulse entered the Bose–Einstein condensate in the presence of the strong control laser. Through EIT, the pulse slowed down and became a dark-state polariton. While the polariton was completely inside the condensate, the experimentalists adiabatically reduced the intensity of the control laser. The reduction was performed in a way that the quantum coherence of the system was maintained.

As the control laser became weaker:

- the photonic component of the polariton decreased,
- the atomic spin-wave component increased,
- the velocity of the polariton decreased further.

Finally, when the control laser was turned off completely, the medium became opaque to probe pulse. The polariton stopped moving. The photonic part of polariton got imprinted as coherent atomic excitations in condensate atoms. The transformation of DSP into spin-wave/matter wave was complete. The light pulse transformed into a stationary atomic spin wave.

Where Did the Information Go?

The most remarkable aspect of this experiment is that although the light disappeared, its information remained. A light pulse carries much more than energy. It carries its complete quantum state: phase, amplitude, temporal shape and polarization.

All these properties were transferred to the collective atomic excitations. Millions of atoms in the condensate participated together in coherence to store the information. The storage was therefore not like writing information into a single atom. It was more like recording a hologram, where information is distributed throughout the entire recording medium.

The BEC acted as a quantum memory.

Retrieving the Stored Light

After a suitable storage time, the control laser was switched on again. The atomic spin wave, which had been holding the information, interacted with the control field. The reverse process—the inverse Raman process—now took place.

Atoms in the state s absorbed photons from the control laser and returned to the ground state g. During this process, the stored atomic excitation was converted back into the electromagnetic field of the probe pulse. A dark-state polariton was recreated. It then began moving through the condensate at low speed of 17 m/s.

When it reached the edge of the condensate, the remaining atomic spin wave component was completely converted into light. The original pulse emerged into free space travelling once again at 299,792 km/s.

Most remarkably, the retrieved pulse retained the essential characteristics of the original pulse:

- the same pulse shape,
- the same phase,
- the same amplitude,
- and the same quantum signature.

The Physics in One Sentence

The entire stopped-light experiment can be summarized as:

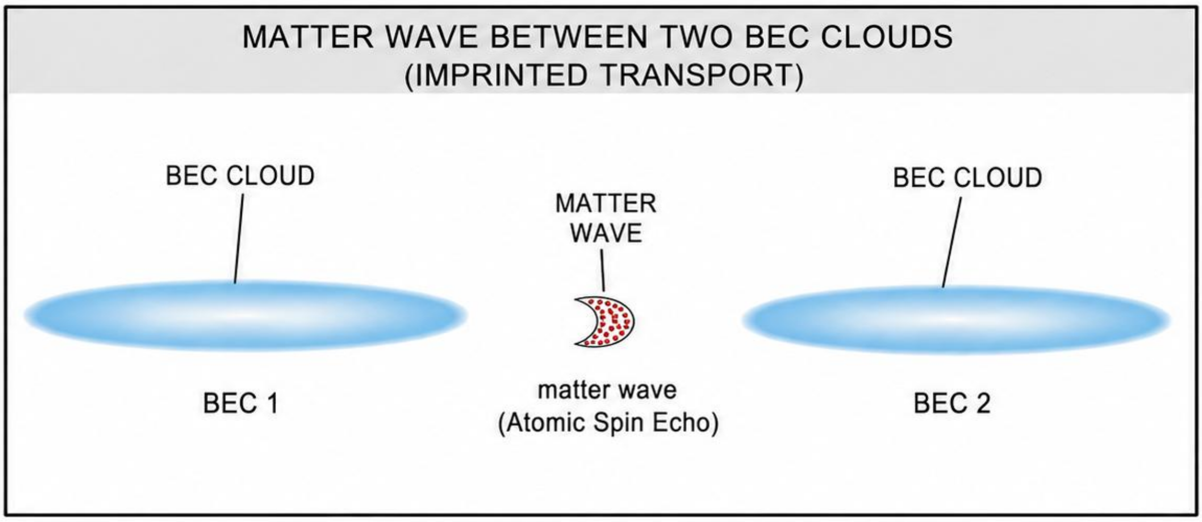
Light → Dark-state polariton → Atomic spin wave → Dark-state polariton → Light

The control laser only acted like a switch that changed the identity of the polariton.

3. The 2007 Experiment: Light Transported as Matter Between Two Bose–Einstein Condensates and Retrieved

The 2001 experiment established a remarkable fact: a pulse of light could be converted completely into an atomic spin wave, stored in matter, and later reconstructed as light.

This achievement naturally led to an even deeper question:



If the identity of light can be stored in matter, **can that matter carrying the light information be physically transported to another location before the light is recreated?**

In 2007, Lene Hau and her team answered this question with another extraordinary experiment. They converted a light pulse into a matter wave in one BEC, transported that matter wave through empty space to a second BEC, and finally reconstructed the original light pulse with the help of control beam.

This was not the movement of photons from one place to another. What travelled between the two condensates was atomic matter (matter wave/spin wave) carrying the quantum signature of light.

The Two-Condensate Experiment

The experiment used two separate Bose–Einstein condensates of sodium atoms, placed a short distance apart, in an ultra-high vacuum chamber.

- The probe pulse first entered BEC1 in the presence of the control laser. The condensate turned transparent to the probe pulse. The pulse slowed down, it became a dark-state polariton. When the entire polariton was inside BEC1, the control laser was switched off. The light component disappeared. The optical information was stored as a collective atomic spin wave. Up to this point, the experiment was identical to the stopped-light experiment. The next step was the truly remarkable one.

The Light Information Travels as Matter

When the light pulse was converted into matter (a spin wave/matter wave) the atoms carrying this excitation received a small momentum kick due to conservation of momentum during the Raman process. The atoms, not light, began to move in the direction of the original probe pulse.

A small packet of atoms carrying the stored optical information separated from the parent condensate. This travelling packet was a matter wave. Its speed was extremely small, only about 2.5 cm/s. Although this speed appears very slow, it was sufficient for the atoms to travel across the small gap separating the two condensates.

The atoms crossed empty space and entered the second Bose–Einstein condensate.

The transported entity between BEC1 and BEC2 was not a light pulse. It was a coherent atomic matter wave carrying the quantum information originally encoded in light.

How Could the Information Survive the Journey?

At first sight, transporting a delicate quantum state through space seems almost impossible. Any disturbance could destroy the phase coherence of the spin wave.

However, several factors like vacuum, ultra cold temperature and quantum coherence of the condensate made such secure quantum transition possible.

Recreating the Light in the Second Condensate

Once the travelling matter wave entered BEC2, the control laser on the second condensate was switched on. The inverse Raman process began—atoms carrying the spin-wave excitation absorbed photons from the control laser and returned from state s to state g.

During this process, the stored atomic excitation was converted back into the electromagnetic field. A dark-state polariton was recreated inside BEC2. The polariton travelled slowly through the second condensate at about 17 m/s.

When it reached the boundary of the condensate, the atomic component was transformed into light completely and emerged as pure light. It immediately accelerated back to its normal speed, 299,792 km/s, travelling in free space.

This regenerated pulse was essentially a faithful copy of the original pulse. Its shape, amplitude, phase and quantum signature were preserved.

The Complete Journey of the Light Pulse

The pulse began as light.

- In BEC1 it first became DSP.
- Then transformed into a spin wave/matter wave (atomic memory).
- The matter wave travelled through space.

- It entered BEC2 as a spin wave and was transformed into DSP.
- On exit from BEC2 (memory recalled) it became a light pulse again.

Yet the information carried by the original pulse survived unchanged.

Conclusion

These experiments revealed:

"Light and matter are not completely separate worlds."

Under suitable quantum conditions, they can continuously exchange their character. A photon can lend its identity to atoms, and atoms can later return that identity back to light. The boundary between light and matter becomes flexible rather than rigid.

Lene Hau demonstrated that just as a sculptor shapes a piece of material by carefully controlling its form, quantum physicists can now shape the behavior of light by controlling its interaction with matter.

The ability to convert light into matter and back again has enormous importance for future technologies. Modern communication systems rely heavily on optical signals but quantum information processing requires new ways of storing and manipulating quantum states.

The experiments of Lene Hau provide a foundation for quantum memories, quantum communications and quantum information processing.

Final Reflection

Perhaps the most profound message from these experiments is that nature does not always obey our classical intuition. In the quantum world, light and matter are not rigidly separated. They are two interconnected expressions of the same underlying quantum reality.

And in that elegant dance between photons and atoms, Lene Hau's experiments revealed one of the most beautiful faces of light.

Key Message

LIGHT THAT TRAVELS WITH ULTIMATE SPEED AND WITHOUT REST WHEN LEFT FREE IN UNIVERSE CAN BE NOW MADE TO WALK, CRAWL AND EVEN STOP.

References

1. Harris, S. E. (1997). *Electromagnetically Induced Transparency*. *Physics Today*, 50(7), 36–42.
2. Anderson, M. H., Ensher, J. R., Matthews, M. R., Wieman, C. E., & Cornell, E. A. (1995). *Observation of Bose–Einstein Condensation in a Dilute Atomic Vapor*. *Science*, 269(5221), 198–201.
3. Hau, L. V., Harris, S. E., Dutton, Z., & Behroozi, C. H. (1999). *Light Speed Reduction to 17 Metres per Second in an Ultracold Atomic Gas*. *Nature*, 397, 594–598.
4. Liu, C., Dutton, Z., Behroozi, C. H., & Hau, L. V. (2001). *Observation of Coherent Optical Information Storage in an Atomic Medium Using Halted Light Pulses*. *Nature*, 409, 490–493.
5. Braje, D. A., Dutton, Z., Slowe, C., & Hau, L. V. (2003). *Use of Coherent Population Transfer to Control and Redirect Light Pulses in a Bose–Einstein Condensate*. *Physical Review A*, 68, 041801(R).

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ACADEMIC ACTIVITIES OF KPA MEMBERS

Academic Activities of H. D. Ananda ***(15 April 2026 – 15 July 2026)***

- 16th Apr 2026: Delivered an invited talk at Siddaganga Institute of Technology, Tumkur on two topics, namely "Overview of Indian space program" and "Quantum Computing and applications" with a video demonstration.

- 26th Apr 2026: Delivered a talk at summer school held at Dharwad for high school students on the topic "Overview of Indian space program" with a video demonstration.

- 27th Apr 2026: Delivered an invited talk at Mindwave Edu Hub at Dharwad for high school teachers on the topic "Overview of Indian space program" with a video demonstration.

- 29th Apr 2026: Delivered an invited talk at Maharaja Institute of Technology, Mysore on "Quantum Computing and applications in AI, ML and Deep learning" with a video demonstration.

- 12th May 2026: Delivered a talk by Webinar organized by Planet Aerospace on "Fundamentals of Quantum Computing".

- 13th May 2026: Delivered an invited talk at Reva University, Bengaluru on "Quantum Computing and applications in Bio Technology, Drug Discovery and Space Biology".

- 18th June 2026: Delivered an invited talk at Bangalore Institute of Technology, Bengaluru for a one-day workshop on "Quantum Computing and applications in AI, ML and Deep learning"

- 04th July 2026: Delivered an invited talk at BIT Convent, RR Nagar, Bengaluru on "Overview of Indian Space program" with a video demonstration

LIST OF WEBINARS HELD FROM 1 MAY 2026 TO 31 JULY 2026

Sl. No.	Date	Speaker	Topic
1.	03.05.2026	Dr. A. Chandrashekaran	Mineralogy of Radioactivity of Coal and Ash near Thermal Power Plants in Tamil Nadu
2.	10.05.2026	Dr. Ajith Kumar Kolar	Energy Security in India – Challenges and Opportunities
3.	17.05.2026	Dr. Prakash Tirumali	Tsunami and Their Effects on Coast
4.	24.05.2026	Dr. Elangovan Raj Gopalan	Space Science in Medicine
5.	31.05.2026	Dr. Aswin Sai Narayan Seshasai	Bacterial Story
6.	07.06.2026	Dr. M. S. Chandrashekara	Environmental Radiation
7.	15.06.2026	Dr. Pornrat Wattankasiwitch	AI and Physics Education
8.	21.06.2026	Dr. K. M. Eshwarappa	New Materials and Neutron Science
9.	28.06.2026	Dr. Elango Lakshmanan	Sustainable Management of Underground Water
10.	05.07.2026	Sitaram Bangalore	Principles and Applications of AI
11.	19.07.2026	Dr. N. S. Vidhyadhiraja	Matter as Wave; From S. N. Bose's Vision to Modern Atom Lasers
12.	26.07.2026	Dr. B. G. Hegde	ESR Spectroscopy and Its Applications