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1. Anne Carson Awarded 2026 Nobel Prize in Literature

Prelims · Prelims · Nobel Prize in Literature 2026 · The Hindu

Prelims — Current events of national and international importance



Flight from boredom

Anne Carson

Moving seamlessly between the ancient and the contemporary, the Canadian writer's works blur the boundaries between scholarship, poetry, and prose

Radhika Santhanam

ILLUSTRATION: SREEJITH R. KUMAR

In *Plainwater* (1995), the Canadian poet and classicist Anne Carson writes, "I will do anything to avoid boredom. It's the task of a lifetime." Asked once in an interview with *Brick, A Literary Journal* why she fears boredom so much, she replied, "Largely because it's the condition next to death."

Carson, 76, has spent a lifetime resisting intellectual stillness and literary categories. Drawing on Greek classics and mythology, she straddles the worlds of poetry, scholarship, and prose, creating works that occupy the unexplored, unnamed spaces between genres. The Swedish Academy, while awarding her the 2026 Nobel Prize in Literature, said, "Almost all her literary production has centred upon the intersection between the philologist's obsession with words and the poet's desire for new meaning."

Born in Toronto in 1950, Carson discovered Sappho at 15, when she came across a bilingual edition of the ancient Greek poet at a shopping mall. A year later, her high-school Latin teacher, recognising her interest, offered to teach her Greek during lunch breaks.

Her passion led to a PhD in classics at the University of Toronto. Over the years, she taught classics, comparative literature, and poetry at universities across the U.S. and Canada. She has called Homer her greatest literary inspiration. Once, when asked which book published that year she had most enjoyed, she replied that she hadn't read any: "Mostly the books I read are published in 500 BC."

Carson's first book, *Eros the Bittersweet* (1986), grew out of her doctoral research on Sappho. It examines desire as stemming as much from longing as from lack. With this book, she began to carve out a distinctive space between classical scholarship and literary imagination.

In 1998, Carson published what arguably remains her best-known and most accessible work, *Autobiography of Red*. Reimagining the ancient Greek myth of Geryon and Herakles as a queer coming-of-age story, it combines poetry and prose to explore desire, vulnerability, and identity.

A life in fragments

Carson did not initially set out to become a poet. "I preferred drawing, but wasn't very good at it," she told *The Guardian*.

Her first book of poetry, *Short Talks* (1992), in fact began as drawings. She added titles, which grew longer, and eventually the drawings disappeared altogether. What was left was a series of brief prose poems, each exploring a subject – from Van Gogh to orchids to walking backwards – through unexpected observations.

In her first essay in *Men in the Off Hours* (2000), a collection of short poems, translations from ancient Greek and Latin, epitaphs, interviews, and other forms, she uses Thucydides and Virginia Woolf to talk about time, an example of her use of strange juxtapositions. It was when she was writing this collection that her mother died, becoming the subject of the closing piece in the book. Asked once by the Louisiana Channel about writing about people in her own life, Carson said she was appalled by it. "I am determined not to do that, but you have no other understanding of reality except the one you've lived. I don't have imagination and cannot make up stories."

In 2001, she published *The Beauty of the Husband*, a semi-autobiographical work of narrative verse about the painful collapse of a marriage. In it, the speaker says her husband spitefully grabbed her books and took them away after their marriage ended; Carson later revealed that her own husband did the same, but returned them later. It won her the T.S. Eliot Prize, making her the first woman to receive the award.

Carson has always guarded her personal life, except when she published an essay in *The London Review of Books* announcing that she suffers from Parkinson's disease and bemoaning that it had affected her handwriting. When the Swedish Academy contacted her, she said she had been avoiding phone calls from everyone and was planning to go for a walk in the forest with her husband in Iceland, where she also holds citizenship.

WHY IN NEWS

The Swedish Academy awarded the 2026 Nobel Prize in Literature to Canadian poet and classicist Anne Carson. The award brought renewed attention to her genre-defying body of work spanning classical scholarship, poetry, and prose over four decades.

Why the Swedish Academy Chose Her

- The Academy cited her work as centred on the **intersection between the philologist's obsession with words and the poet's desire for new meaning**.
- Carson **blurs genre boundaries** — moving between scholarship, poetry, and prose — a quality the Academy described as defining almost all her literary production.
- Her works draw extensively on **Greek classics and mythology**, reinterpreting ancient texts through a contemporary lens.
- She is recognised for occupying **unnamed spaces between genres**, resisting conventional literary categorisation throughout her career.

Major Works and Their Significance

- **Eros the Bittersweet** (1986), her first book, grew from doctoral research on Sappho and argued that desire stems as much from longing as from lack.
- **Autobiography of Red** (1998) reimagines the Greek myth of Geryon and Herakles as a queer coming-of-age narrative combining poetry and prose.
- **Men in the Off Hours** (2000) blends short poems, ancient Greek and Latin translations, epitaphs, and interviews, deploying unexpected juxtapositions of classical and modern voices.
- **The Beauty of the Husband** (2001), a semi-autobiographical work in narrative verse, won the **T.S. Eliot Prize**, making Carson the **first woman to receive that award**.
- Her debut poetry collection **Short Talks** (1992) originated as drawings, evolving into brief prose poems on subjects ranging from Van Gogh to orchids.

Life and Academic Background

- Born in **Toronto in 1950**, Carson encountered the ancient Greek poet Sappho at age 15 through a bilingual edition found at a shopping mall.
- She completed a **PhD in classics at the University of Toronto** and subsequently taught classics, comparative literature, and poetry at universities across the United States and Canada.
- Carson holds **Icelandic citizenship** in addition to Canadian nationality.
- She publicly disclosed suffering from **Parkinson's disease** in an essay in *The London Review of Books*, noting its effect on her handwriting.

HIGH-YIELD FACTS

- **Award** — Nobel Prize in Literature 2026
- **Laureate** — Anne Carson, Canadian poet and classicist
- **Born** — Toronto, 1950 (age 76 at time of award)
- **Awarding body** — The Swedish Academy
- **T.S. Eliot Prize distinction** — First woman to receive the T.S. Eliot Prize (for The Beauty of the Husband, 2001)
- **First book** — Eros the Bittersweet, 1986
- **Best-known work** — Autobiography of Red, 1998
- **Citizenships** — Canadian and Icelandic

VALUE ADDITION

EXAMPLES FOR THE ANSWER

The T.S. Eliot Prize, awarded by the Poetry Book Society (UK), illustrates how major Anglophone literary prizes can be used to track firsts in gender representation — analogous to how Nobel Prize firsts are tracked for diversity in science and literature.

Carson's use of ancient Greek and Latin sources alongside modern writers such as Virginia Woolf exemplifies the classical reception tradition, a comparative method relevant when answering questions on the relationship between ancient civilisations and contemporary culture.

2. Navi Pillay Awarded Nobel Peace Prize 2026

GS-II · Prelims + Mains · International justice institutions and Nobel Peace Prize · The Hindu

Syllabus — Important International institutions, agencies and fora- their structure, mandate

Prelims — Current events of national and international importance



The jurist and a redemption

Navi Pillay

The Nobel Peace Prize for 2026 is as much a recognition of the South African jurist's lifelong commitment to justice for the oppressed and the powerless as it is a rebuke to the idea that might is right

THE GIST

WHY IN NEWS

The Norwegian Nobel Committee awarded the 2026 Nobel Peace Prize to South African jurist Navanethem 'Navi' Pillay. The award was announced alongside a pointed statement by the Committee about the erosion of international legal frameworks and the sanctioning of ICC officials by the U.S. since 2025, making the prize a deliberate act of institutional reaffirmation rather than merely a biographical honour.

The Career Behind the Prize

- Pillay was born in **1941 in Durban** into a Tamil family whose grandparents had come from India as indentured labourers; she became the **first woman to open a law practice** in Natal province in 1967.
- During apartheid she defended political prisoners and won Robben Island inmates, including **Nelson Mandela**, the right to legal representation.
- She earned a **doctorate from Harvard** and campaigned for the equality clause in South Africa's post-apartheid Constitution.
- Nominated by President Mandela in **1995**, she served eight years on the **International Criminal Tribunal for Rwanda (ICTR)**, four as president, helping deliver landmark rulings that rape and sexual violence can constitute genocide (*Akayesu* case) and that radio hate propaganda inciting genocide is criminal (*Media* case).
- She subsequently served as an **ICC judge (2003–08)**, as **UN High Commissioner for Human Rights (2008–14)**, and most recently as **chair of the UN Commission of Inquiry on the Occupied Palestinian Territory (2021–25)**.

What the Committee Was Really Saying

- The Committee's citation declared that peace **'must be built on legal principles, not on the will of the strong'**, a phrase widely read as a rebuke to the doctrine — attributed in Plato's *Republic* to **Thrasymachus** — that justice is merely the advantage of the stronger.
- It warned of a shift toward power politics at the expense of legal frameworks and of judges whose institutions are **'attacked'** — a clear reference to U.S. sanctions on ICC officials imposed since 2025.
- The timing was pointed: the prize was announced **on the same day** the U.S. sanctioned additional ICC officials, framing the honour as a direct institutional counter-signal.
- The Committee described judges as **'those who guard the thin red line between order and chaos'**, elevating the prize beyond one individual to a defence of the post-1945 international legal order itself.

The Gaza Finding and Its Controversy

- In **September 2025**, Pillay chaired the UN Commission of Inquiry that concluded Israel had committed genocide against Palestinians in Gaza, finding **four of the five acts** listed in the **1948 Genocide Convention** had been committed since October 2023.
- The Commission documented a siege it concluded was **'designed to starve the population to death'**, while also documenting Hamas atrocities of **October 7**, stating explicitly that **'no crime, however grave, justifies genocide'**.
- Pillay drew on her direct experience at the ICTR — where she presided over the conviction of three Rwandans for genocide — to explain the precision with which she uses the word.
- The reaction from Israel and the U.S. was sharp: Israel called the prize **'grotesque weaponisation'** of the Nobel award, while the Committee chair noted the Nobel Committee is not a court but sent a message by honouring the jurist who named the crimes.

Two Threats to the International Order

- The article identifies a **developed-world threat**: a major power using military superiority to seize resources and dismantle restraining institutions, citing the abduction of Venezuela's president and the attack on Iran in early 2026.
- It identifies a **Global South threat**: authoritarian regimes such as Myanmar's junta waging violence against their own citizens — including the expulsion of **lakhs of Rohingya since 2017** — with scarcely a world response.
- Both dynamics share a common ideological root: **'faith in power and in might being right'**, which the prize is framed as a corrective against.
- The article argues that in such a climate the burden falls on **jurists of international courts and human rights investigators** to name illegal acts accurately, even when their findings are non-binding.

The Nobel Committee's Credibility at Stake

- The Committee had faced criticism the previous year when it honoured **Venezuelan Opposition leader María Corina Machado**, a U.S. ally; she subsequently gifted the medal to the U.S. president at the White House, embarrassing the body by implying the prize could be transferred.

- Honouring Pillay — whose findings directly challenge the same U.S. administration — is read as the Committee **correcting its own course** and reaffirming that the prize recognises commitment to international law over geopolitical alignment.
- The article notes the Nobel Committee is **'not the court'** but argues it has the power to confer legitimacy on norms the court cannot enforce, making the choice of recipient itself a form of soft norm-enforcement.

HIGH-YIELD FACTS

- **Prize year** — Nobel Peace Prize 2026 awarded to Navanethem 'Navi' Pillay
- **Birth** — Born 1941, Durban, South Africa, in a Tamil family of Indian-origin indentured-labourer descent
- **ICTR role** — Served on International Criminal Tribunal for Rwanda 1995–2003, including four years as president
- **Akayesu case** — ICTR ruled in the Akayesu case that rape and sexual violence can constitute genocide — landmark ruling under Pillay's court
- **Media case** — ICTR ruled in the Media case that spreading hate propaganda against Tutsis by radio and print was incitement to genocide
- **UN HCHR tenure** — UN High Commissioner for Human Rights, 2008–2014
- **Gaza Commission** — Chair, UN Commission of Inquiry on the Occupied Palestinian Territory, 2021–2025
- **ICJ role** — Sits as ad hoc judge designated by The Gambia in the International Court of Justice genocide case against Myanmar

VALUE ADDITION

DATA YOU CAN QUOTE

Acts of genocide found by Pillay's Commission in Gaza — 4 of the 5 acts listed in the 1948 Genocide Convention, as of October 2023 onwards

Prize's institutional age — 125-year history of the Nobel Peace Prize at the time of the 2026 award

Rohingya expelled since 2017 — Lakhs of Rohingya expelled by Myanmar junta since 2017 — cited as emblematic of Global South impunity

REPORTS, BODIES AND INSTRUMENTS

Convention on the Prevention and Punishment of the Crime of Genocide, 1948 (UN)

UN Commission of Inquiry on the Occupied Palestinian Territory (UN Human Rights Council, 2021–2025)

Rome Statute of the International Criminal Court, 1998

Prosecutor v. Akayesu, ICTR-96-4-T — International Criminal Tribunal for Rwanda

The Media Case (Prosecutor v. Nahimana et al.), ICTR-99-52-T — International Criminal Tribunal for Rwanda

EXAMPLES FOR THE ANSWER

The Akayesu judgment (ICTR, 1998) established for the first time in international law that rape used as a tool of ethnic destruction constitutes an act of genocide — applicable when answering questions on the evolution of international humanitarian law.

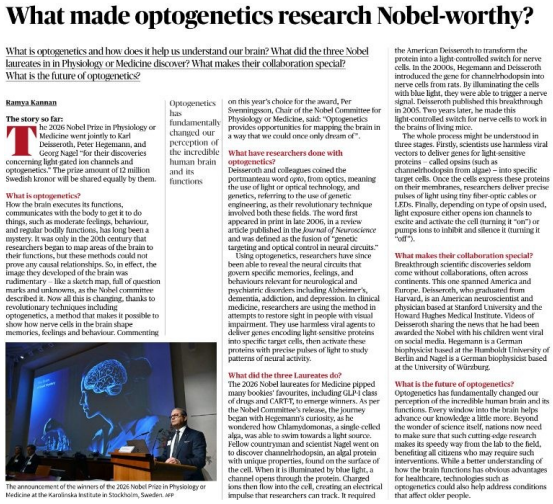
The Nobel Committee's implicit reversal after the Machado episode illustrates how prize-giving bodies can use award sequencing to recalibrate perceived political bias — relevant to questions on soft-power and norm-signalling by international institutions.

The post-1945 multilateral legal order — the UN Charter, the Genocide Convention, the ICC — was built precisely to restrain might-makes-right logic; the current U.S.-ICC standoff is a live stress-test of whether that order is self-enforcing or dependent on great-power consent, a theme directly examinable under 'challenges to multilateralism'.

3. Optogenetics and the 2026 Nobel Prize in Physiology

Prelims · Prelims + Mains · Optogenetics Nobel Prize 2026 · The Hindu

Prelims — General Science — Biology and biotechnology; Current events of national and international importance



What made optogenetics research Nobel-worthy?

What is optogenetics and how does it help us understand our brain? What did the three Nobel laureates in in Physiology or Medicine discover? What makes their collaboration special? What is the future of optogenetics?

Ramya Kannan

The story so far: The 2026 Nobel Prize in Physiology or Medicine went jointly to Karl Deisseroth, Peter Hegemann, and Georg Nagel "for their discoveries concerning light-gated ion channels and optogenetics." The prize amount of 12 million Swedish kronor will be shared equally by them.

What is optogenetics?

How the brain executes its functions, communicates with the body to get it to do things, such as moderate feelings, behaviour, and regular bodily functions, has long been a mystery. It was only in the 20th century that researchers began to map areas of the brain to their functions, but these methods could not prove any causal relationships. So, in effect, the image they developed of the brain was rudimentary – like a sketch map, full of question marks and unknowns, as the Nobel committee described it. Now all this is changing, thanks to revolutionary techniques including optogenetics, a method that makes it possible to show how nerve cells in the brain shape memories, feelings and behaviour. Commenting on this year's choice for the award, Per Svenningsson, Chair of the Nobel Committee for Physiology or Medicine, said: "Optogenetics provides opportunities for mapping the brain in a way that we could once only dream of".

Optogenetics has fundamentally changed our perception of the incredible human brain and its functions

What have researchers done with optogenetics?

Deisseroth and colleagues coined the portmanteau word opto, from optics, meaning the use of light or optical technology, and *genetics*, referring to the use of genetic engineering, as their revolutionary technique involved both these fields. The word first appeared in print in late 2006, in a review article published in the *Journal of Neuroscience* and was defined as the fusion of "genetic targeting and optical control in neural circuits."

Using optogenetics, researchers have since been able to reveal the neural circuits that govern specific memories, feelings, and behaviours relevant for neurological and psychiatric disorders including Alzheimer's, dementia, addiction, and depression. In clinical medicine, researchers are using the method in attempts to restore sight in people with visual impairment. They use harmless viral agents to deliver genes encoding light-sensitive proteins into specific target cells, then activate these proteins with precise pulses of light to study patterns of neural activity.

What did the three Laureates do?

The 2026 Nobel laureates for Medicine pipped many bookies' favourites, including GLP-1 class of drugs and CAR-T, to emerge winners. As per the Nobel Committee's release, the journey began with Hegemann's curiosity, as he wondered how Chlamydomonas, a single-celled alga, was able to swim towards a light source. Fellow countryman and scientist Nagel went on to discover channelrhodopsin, an algal protein with unique properties, found on the surface of the cell. When it is illuminated by blue light, a channel opens through the protein. Charged ions then flow into the cell, creating an electrical impulse that researchers can track. It required the American Deisseroth to transform the protein into a light controlled switch for nerve cells. In the 2000s, Hegemann and Deisseroth introduced the gene for channelrhodopsin into nerve cells from rats. By illuminating the cells with blue light, they were able to trigger a nerve signal. Deisseroth published this breakthrough in 2005. Two years later, he made this light-controlled switch for nerve cells to work in the brains of living mice.

The whole process might be understood in three stages. Firstly, scientists use harmless viral vectors to deliver genes for light-sensitive proteins – called opsins (such as channelrhodopsin from algae) – into specific target cells. Once the cells express these proteins on their membranes, researchers deliver precise pulses of light using tiny fiber-optic cables or LEDs. Finally, depending on type of opsin used, light exposure either opens ion channels to excite and activate the cell (turning it "on") or pumps ions to inhibit and silence it (turning it "off").

What makes their collaboration special?

Breakthrough scientific discoveries seldom come without collaborations, often across continents. This one spanned America and Europe. Deisseroth, who graduated from Harvard, is an American neuroscientist and physician based at Stanford University and the Howard Hughes Medical Institute. Videos of Deisseroth sharing the news that he had been awarded the Nobel with his children went viral on social media. Hegemann is a German biophysicist based at the Humboldt University of Berlin and Nagel is a German biophysicist based at the University of Würzburg.

What is the future of optogenetics?

Optogenetics has fundamentally changed our perception of the incredible human brain and its functions. Every window into the brain helps advance our knowledge a little more. Beyond the wonder of science itself, nations now need to make sure that such cutting-edge research makes its speedy way from the lab to the field, benefiting all citizens who may require such interventions. While a better understanding of how the brain functions has obvious advantages for healthcare, technologies such as optogenetics could also help address conditions that affect older people.

The announcement of the winners of the 2026 Nobel Prize in Physiology or Medicine at the Karolinska Institute in Stockholm, Sweden. AFP

WHY IN NEWS

The 2026 Nobel Prize in Physiology or Medicine was awarded jointly to Karl Deisseroth, Peter Hegemann, and Georg Nagel for their discoveries concerning light-gated ion channels and optogenetics. The prize, worth 12 million Swedish kronor shared equally, was announced at the Karolinska Institute in Stockholm.

What Optogenetics Actually Is

- **Optogenetics** is a method that uses light to control the activity of individual nerve cells, making it possible to show how specific neurons shape memories, feelings, and behaviour.
- The portmanteau word *opto* was coined by Deisseroth and colleagues — combining **optics** (light/optical technology) and **genetics** (genetic engineering) — and first appeared in print in late 2006 in the *Journal of Neuroscience*.
- It was formally defined as the fusion of **genetic targeting and optical control in neural circuits**, marking a departure from older mapping methods that could describe brain regions but could not prove causal relationships.
- The core tool is a class of light-sensitive proteins called **opsins** (e.g., channelrhodopsin from algae), which, when expressed in a target cell and exposed to light, either open ion channels to activate the cell ('on') or pump ions to silence it ('off').

The Three Laureates and Their Discoveries

- **Georg Nagel** (University of Würzburg) built on Hegemann's curiosity about how the single-celled alga *Chlamydomonas* could swim toward light, discovering **channelrhodopsin** — an algal protein on the cell surface that opens a channel when illuminated by blue light, allowing charged ions to flow in and create a trackable electrical impulse.
- **Peter Hegemann** (Humboldt University of Berlin) initiated the enquiry into *Chlamydomonas* photobehaviour, establishing the biological foundation from which channelrhodopsin was isolated.
- **Karl Deisseroth** (Stanford University / Howard Hughes Medical Institute) introduced the channelrhodopsin gene into rat nerve cells; by illuminating them with blue light he could **trigger a nerve signal** — a breakthrough published in 2005.
- Two years after that publication, Deisseroth made the light-controlled switch work in the brains of **living mice**, crossing the threshold from cell culture to intact organisms.
- The collaboration spanned **America and Europe**, with Hegemann and Nagel working in Germany and Deisseroth in the United States — a transatlantic partnership the Nobel Committee highlighted as emblematic of how major discoveries form.

How Researchers Deploy the Technology

- Scientists use **harmless viral vectors** to deliver genes for opsins into specific target cells; once expressed on cell membranes, precise pulses of light via **fibre-optic cables or LEDs** activate or silence those cells on demand.
- Optogenetics has revealed the neural circuits governing **specific memories, feelings, and behaviours**, and is a key research tool for understanding Alzheimer's disease, dementia, addiction, and depression.
- In **clinical medicine**, researchers are using the method to attempt to restore sight in people with visual impairment by delivering genes encoding light-sensitive proteins into target cells in the eye.
- The technology's precision — targeting individual cell types rather than broad brain regions — represents a qualitative advance over prior methods that could only correlate anatomy with function, not establish causation.

Limits and What Comes Next

- Optogenetics has **fundamentally changed** the conceptual map of the brain, moving it from a sketch full of question marks to a circuit diagram where causal claims can be tested.
- A key unresolved challenge is the **translation from lab to field**: ensuring cutting-edge research benefits citizens who need clinical interventions, not just advancing basic science.
- The technology's ability to illuminate brain function holds obvious promise for **healthcare in ageing populations**, particularly for neurological and psychiatric conditions that disproportionately affect older people.
- The 2026 prize surpassed bookmakers' favourites including **GLP-1 drug class research and CAR-T therapy**, underscoring how foundational neuroscience tools can be judged Nobel-worthy alongside more clinically visible interventions.

HIGH-YIELD FACTS

- **Prize year** — 2026 Nobel Prize in Physiology or Medicine
- **Laureates** — Karl Deisseroth, Peter Hegemann, and Georg Nagel
- **Prize citation** — Discoveries concerning light-gated ion channels and optogenetics
- **Prize amount** — 12 million Swedish kronor, shared equally among the three
- **Announced at** — Karolinska Institute, Stockholm, Sweden
- **Term coined** — Word 'optogenetics' first appeared in print in late 2006, in the Journal of Neuroscience
- **Key protein** — Channelrhodopsin — an algal protein found on the surface of Chlamydomonas, a single-celled alga
- **Deisseroth breakthrough published** — 2005 — nerve-signal triggering via channelrhodopsin in rat cells; 2007 — demonstrated in living mice

VALUE ADDITION

REPORTS, BODIES AND INSTRUMENTS

Nobel Committee for Physiology or Medicine, Karolinska Institute — annual prize citation and scientific background document

EXAMPLES FOR THE ANSWER

Channelrhodopsin's use in restoring vision parallels cochlear implants, illustrating how basic sensory-neuroscience research (mapping how hair cells transduce sound) can become a clinical prosthetic — useful when arguing for funding basic science.

The transatlantic Hegemann–Nagel–Deisseroth collaboration mirrors the DNA double-helix story (Watson and Crick in Cambridge, Franklin's X-ray data), showing how distributed, multi-national teams repeatedly produce paradigm-shifting discoveries — a point for science-diplomacy questions.

4. 2026 Nobel Chemistry Prize: Chirality and Asymmetric Catalysis

GS-III · Prelims + Mains · Chirality, asymmetric catalysis, drug development · The Hindu

Syllabus — Science and Technology- developments and their applications and effects in everyday life

Prelims — Science and Technology — Chemistry, Nobel Prize 2026



What was the Chemistry Nobel Prize given for?

What are chirality and molecular 'handedness' and why does life favour one form over the other? Why does the handedness of a molecule matter when developing drugs? What did Henri Kagan and Kenso Soai discover? Can it explain the origins of life?

Jacob Koshy

The story so far:

The 2026 Nobel Prize in Chemistry has been awarded to Henri Kagan and Kenso Soai for showing that it is possible to amplify a molecule's "handedness" and direct it in a way that it can be used to produce pharmaceutical products of a very high purity. Their work also offers clues to explaining how life on earth could have evolved from simple molecules.

What are chirality and "handedness"?

Your left and right hand have the same number of fingers. Both have ring fingers and thumbs of the same length. Yet why can't you wear the left hand's glove on the right? The reason is 'chirality,' from the Greek word kheir, which means hand. It is the geometric property of an object or molecule that makes it non-superimposable on its mirror image.

Many chemical molecules that make up substances also possess this property of chirality. The mirror images of a molecule – the left glove and right glove so to say – are called enantiomers. Yet the organic molecules that make up living organisms are overwhelmingly either left-handed or right-handed, rather than occurring in 50:50 proportions. This property, of homochirality, is as if a fashion house decided to base its entire business on making only left-handed gloves and accessories to match. Or, as we observe in daily life, most people are right-handed, and urban fixtures such as door knobs seem designed with them in mind.

Every amino acid, the building blocks of protein, comes in the "left" (L) form and every sugar in your DNA the "right" (D) form. What is the puzzle? It is that ordinary laboratory reactions, though, often produce equal amounts of both enantiomers – a 50:50 mix known as a racemate. The French chemist Louis Pasteur observed this as far back as 1848, when bacteria devoured one mirror form of tartaric acid and left the other untouched.

This was the first time anyone had made a one-handed product from non-chiral ingredients in this way, and the reaction remains the only known example of its kind

Why does chirality matter to the pharmaceutical industry?

A drug works by attaching to the surface of enzymes or receptors – just like a password is required for a lock. In the world of enantiomers, the same letters of the password in the wrong order can at best be harmless and at worst be harmful – repeatedly entering the wrong password can lock you out of a system.

The drug thalidomide offers a cautionary tale. First marketed as a sedative, it left thousands of children with birth defects in the early 1960s. For a long time, these defects were attributed to the presence of both enantiomers. However, subsequent analysis says that is only part of the explanation. The broader principle is that enantiomers matter.

Ethambutol, a first-line tuberculosis drug, is another example. Its (S,S) form is about 500 times more potent against the tuberculosis bacillus than its (R,R) mirror image. Yet optic-nerve damage, a serious side effect of the drug, is associated with dose and duration of treatment. Producing a purer form of the more potent enantiomer could therefore allow lower doses, potentially reducing patients' exposure to the drug and its side effects. The challenge is how to manufacture the desired enantiomer with sufficient purity.

What was Frank's model and how was it tested?

In 1953, Charles Frank, a theoretical physicist at the University of Bristol, used mathematics to analyse why the molecules of life acquired their bias towards one handedness. His model needed three things: a substance that catalyses its own production (autocatalysis); a catalyst that favours one hand (enantioselective catalysis); and an "anti-catalyst" that suppresses its mirror image. Combine them and even a tiny initial difference, where one form is present slightly more than the other, snowballs exponentially. It took decades. Autocatalysis was already known. Asymmetric, or enantioselective catalysis, had already earned Nobel Prizes in 2001 and 2021. What nobody had shown was mutual antagonism, or the marriage of autocatalysis and asymmetry, and this was where Kagan, in 1986, and Soai, in 1995, made their contribution.

What did each laureate do, and what set them apart?

Kagan, then at Paris Sud, challenged a dogma. Chemists believed that for more product purity, more of a catalyst's chiral ingredient had to be proportionally pure. Therefore the race was for ever purer ingredients. Kagan asked what the metal in a catalyst actually does, and reasoned that it grips not one but two chiral molecules (the "ligands" that give the catalyst its handedness). Suppose you build the catalyst from a mix of the two enantiomers – say 75% right-handed and 25% left-handed – the metal picks its two partners at random, so three kinds of catalyst form: right-right (about 56%), left-left (about 6%) and a mixed right-left pair (about 38%). The two matched pairs work well. The mixed pair barely works at all, so it sits idle and takes its share of both hands out of play. Because the minority hand mostly ends up paired with a majority-hand partner in an idle mixed complex, left-left catalysts are rare, and the reaction is driven almost entirely by right-right ones. The product comes out roughly 90:10 in favour of the right hand, purer than the 75:25 mix you started with.

This overturned the old assumption that a product could be no purer than the catalyst's ingredients. Kagan's distinction was therefore twofold. He found a new rule – that purity can be amplified and he also gave chemists a diagnostic to determine how many ligands a catalyst could hold and which forms do the work. Soai's contribution was to build the reaction Frank had imagined: a molecule that makes more of itself, and in the process makes itself purer. In his reaction, the product is also the catalyst. Each batch of product is added to the next batch as catalyst, and each round comes out more lopsided than the last. Starting from a pyrimidyl alcohol with a 5% excess of one hand, five rounds lifted it to 90%. In a later version, an excess of just 0.00005%, far too small to measure by ordinary means, became more than 99.5% pure in three rounds. That is an amplification of roughly 6,30,000-fold. Then came the decisive step. Soai showed that no chiral starting point is needed. Begin with ingredients that have no handedness at all, and the reaction ends up almost entirely one-handed over repeated runs, with the hand chosen by chance. This was the first time anyone had made a one-handed product from non-chiral ingredients in this way, and the reaction remains the only known example of its kind.

Is this a model for the evolution of life?

Not quite, and the Nobel Committee itself says so. Frank's model is one possible explanation for how life acquired its molecular handedness 3.5 billion to 4 billion years ago, an event we may never fully understand. Soai's reaction uses zinc reagents in an organic solvent, nothing like the watery "prebiotic soup" in which life is thought to have emerged. The Nobel Committee calls it a "proof of concept".

Kagan and Soai showed that the mechanisms Frank envisaged could work in the lab. Had Frank lived, he might have shared in the prize.

Japanese Nobel laureate Kenso Soai at a press conference in Tokyo. AFP

WHY IN NEWS

The 2026 Nobel Prize in Chemistry was awarded to Henri Kagan and Kenso Soai for demonstrating that a molecule's 'handedness' (chirality) can be amplified and directed to produce pharmaceutical-grade pure products from non-chiral ingredients. The award has brought renewed attention to the role of molecular chirality in drug safety, manufacturing, and theories about the origin of life.

What Chirality Is and Why Life Chose a Side

- **Chirality** (from Greek *kheir*, 'hand') is the geometric property of an object or molecule that makes it non-superimposable on its mirror image — like a left and right glove.
- Mirror-image molecules are called **enantiomers**; ordinary lab reactions typically produce a 50:50 mix (a racemate) of both forms.
- Living organisms are overwhelmingly **homochiral**: protein synthesis predominantly uses L-amino acids, while glycine is achiral and D-amino acids occur, for example, in bacterial cell walls. The sugar in DNA is D-deoxyribose.
- The property of homochirality means biology behaves like a fashion house that stocks only left-handed gloves — the origin of this bias, 3.5–4 billion years ago, remains unexplained.

Why the Wrong Enantiomer Can Kill or Cure

- Drugs work by attaching to **enzymes or receptors**; the correct enantiomer fits the 'lock', while the wrong one can be harmless or actively harmful.
- **Thalidomide** is the cautionary benchmark: used as a sedative in the late 1950s and early 1960s, it caused birth defects in thousands of children. Its enantiomers interconvert under physiological conditions, so separating them alone does not eliminate teratogenic risk.
- **Ethambutol** (a tuberculosis drug) illustrates potency differences: its (S,S) form is 500 times more potent against the TB bacillus than its (R,R) mirror image, yet the (R,R) form causes optic-nerve damage.
- Producing a **purer enantiomer** allows lower doses, reducing side-effect exposure — making asymmetric synthesis a central challenge for the pharmaceutical industry.

Frank's 1953 Model: The Mathematics of Handedness

- In **1953**, theoretical physicist Charles Frank (University of Bristol) used mathematics to model how life's molecules could acquire a bias toward one handedness.

- His model required three elements: a substance that **catalyses its own production** (autocatalysis); a catalyst that **favours one hand** (enantioselective catalysis); and an **anti-catalyst** that suppresses the mirror image.
- With even a tiny initial excess of one form, these combined mechanisms cause that form to **snowball exponentially** — explaining how a small random fluctuation could lock life into one handedness.
- The 2001 Nobel Prize recognised catalytic asymmetric synthesis, and the 2021 prize recognised asymmetric organocatalysis. Neither prize was for autocatalysis; Soai's work demonstrated asymmetric autocatalysis with amplification of enantiomeric excess.

What Kagan and Soai Each Discovered

- **Henri Kagan** (Paris-Sud) challenged the assumption that catalyst purity must match product purity; he showed that a catalyst grips two chiral ligands simultaneously, meaning **purity can be amplified** beyond the purity of the starting catalyst — a twofold diagnostic rule for catalyst design.
- **Kenso Soai**, in **1995**, built on Frank's model by constructing a real molecule that acts as both product and catalyst — a **self-amplifying autocatalytic reaction** where each batch of product seeds the next.
- Starting from a **pyrimidyl alcohol** with a 5% excess of one hand, five reaction rounds lifted enantiomeric excess to 90%. In a later version, about 0.00005% enantiomeric excess (ee) rose to over 99.5% ee in three rounds, while the amount of material multiplied about 6,30,000-fold. The multiplication factor describes the amount of material, not the ratio of final to initial ee.
- Most strikingly, Soai showed the reaction works even with **no chiral starting material at all** — beginning from entirely non-chiral ingredients, repeated runs end up almost entirely one-handed, with the dominant hand chosen by chance. This is the **only known example** of its kind.

What the Prize Does — and Does Not — Explain About Life's Origin

- The Nobel Committee calls Soai's reaction a **'proof of concept'** that Frank's mechanisms can operate in the real world — not proof that life actually arose this way.
- Soai's reaction uses **zinc reagents in an organic solvent**, far removed from the watery 'prebiotic soup' in which early life is thought to have emerged, limiting direct extrapolation.
- The work demonstrates that the **molecular handedness of life** need not require a pre-existing chiral template — chance alone, amplified by autocatalysis, could suffice.
- The Nobel Committee notes that had Frank lived, he might have shared the prize — the award recognises that **theoretical prediction and experimental verification** together constitute the scientific contribution.

HIGH-YIELD FACTS

- **Prize awarded** — 2026 Nobel Prize in Chemistry — Henri Kagan and Kenso Soai
- **Soai's key year** — Kagan's contribution: 1986; Soai's autocatalytic discovery: 1995
- **Frank's model year** — Charles Frank proposed his mathematical model of homochirality in 1953 at the University of Bristol
- **Thalidomide** — A landmark drug-safety case: enantiomers interconvert under physiological conditions, so chiral separation alone does not remove teratogenic risk
- **Ethambutol potency ratio** — (S,S) form is 500 times more potent against TB bacillus than its (R,R) enantiomer
- **Soai amplification** — About 0.00005% ee to >99.5% ee in three rounds; the amount of material multiplied approximately 6,30,000-fold
- **Life's homochirality age** — Estimated to have arisen 3.5–4 billion years ago
- **Prior Nobel context** — Asymmetric catalysis recognised by Nobel in 2001 (catalytic asymmetric synthesis) and 2021 (asymmetric organocatalysis)

VALUE ADDITION

DATA YOU CAN QUOTE

Soai autocatalysis — Enantiomeric excess rose from about 0.00005% to >99.5% in three rounds; ~6,30,000-fold refers separately to multiplication of the amount of material

Ethambutol enantiomer potency gap — (S,S) form 500× more potent than (R,R) mirror image against Mycobacterium tuberculosis

REPORTS, BODIES AND INSTRUMENTS

Nobel Prize in Chemistry 2001 — Royal Swedish Academy of Sciences (asymmetric catalytic hydrogenation and oxidation)

Nobel Prize in Chemistry 2021 — Royal Swedish Academy of Sciences (asymmetric organocatalysis)

EXAMPLES FOR THE ANSWER

Thalidomide (1960s): illustrates why drug regulation must assess stereochemistry, biological activity, and interconversion in the body. Because its enantiomers interconvert physiologically, chiral separation alone cannot ensure safety.

Charles Frank's 1953 autocatalysis model: demonstrates how mathematical modelling of symmetry-breaking preceded experimental validation by over four decades — usable in questions on the theory-experiment relationship in science.

5. IceCube Observatory: Physics Nobel and Neutrino Detection

GS-III · Prelims + Mains · IceCube neutrino detection technology · The Hindu

Syllabus — Science and Technology- developments and their applications and effects in everyday life

Prelims — General Science — Physics, Space and basic science


Why was IceCube founder given the physics Nobel?

WHY IN NEWS

Belgian-American physicist Francis Halzen has been awarded the Nobel Prize in Physics for 2026 for his foundational role in building the IceCube Neutrino Observatory in Antarctica. The award brings renewed attention to how IceCube detects high-energy cosmic neutrinos and what its findings reveal about astrophysical sources in the universe.

Why Neutrinos Are Worth Catching

- **Cosmic rays** — high-energy particles that constantly bombard Earth — are mostly protons or nuclei of elements like helium and iron, but their charged nature means **magnetic fields in space deflect them**, erasing directional information about their sources.
- **Neutrinos** are subatomic particles with no electric charge and very small mass; they interact extremely rarely with matter, pass through the body without leaving a trace, and travel in perfectly **straight lines** — making them ideal messengers from astrophysical sources.
- Nuclear reactions such as **fusion in the sun's belly** and powerful events like colliding stars or jets of matter accelerated by distant galaxies produce neutrinos in copious numbers — trillions pass through the human body every second.

- Because neutrinos point back directly to their source without deflection, detecting a high-energy neutrino from deep space is an **indicator of a high-energy event** — a supernova, an active galactic nucleus, or a gamma-ray burst — that produced it.
- Scientists could not previously confirm what gave cosmic rays a **Herculean push** to energies exceeding anything the Large Hadron Collider achieves; neutrino astronomy offers the clearest route to that answer.

The IceCube Detection Principle

- Halzen and John G. Learned developed the core idea during **1987–1988**: use the enormous volume of Antarctic ice — a natural, ultra-clear medium — as a detector, embedding sensors to watch for light produced when a neutrino strikes an atom.
- When an energetic neutrino strikes a nucleus inside ice, it creates charged particles; some travel faster than light *in that medium*, emitting **Cherenkov radiation** — a faint blue glow that IceCube's sensors record.
- Different sensor readings, combined computationally, reveal the **kind of neutrino interaction**, its energy, and critically its direction, allowing researchers to reconstruct where in the sky it came from.
- IceCube records every year **around a hundred high-energy neutrinos** above its energy cutoff that are consistent with coming from astrophysical sources in outer space, not from local atmospheric processes.
- The project was funded primarily by the **U.S. National Science Foundation**; Halzen organised the effort over decades, coordinating hundreds of scientists and engineers.

How the Instrument Was Built

- IceCube took its full shape in **2011** after seven years of construction, using hot-water drills — not shovels — to bore holes into the Antarctic ice sheet, then lowering sensors and freezing them in place.
- The observatory contains **5,160 optical sensors** on 86 cables, lying 1.4 km to 2.4 km underground, encompassing roughly **a cubic kilometre of ice** — the largest neutrino detector ever built.
- Each sensor converts faint Cherenkov light into an electric signal; collective data flows to surface computers and is transmitted to researchers worldwide, enabling real-time multi-messenger astronomy alerts.
- The ice itself must be extraordinarily clear; IceCube scientists had to characterise the optical properties of deep Antarctic ice carefully to subtract noise and correctly interpret sensor readings.

What IceCube Has Already Found

- In **2013**, IceCube identified two neutrinos with around 140 times the energy of a proton accelerated by the LHC, establishing the first evidence that a high-energy extragalactic neutrino population was reaching Earth — a landmark in neutrino astronomy.
- On 22 September **2017**, IceCube detected a high-energy neutrino associated with **the blazar TXS 0506+056; the evidence** was published in July 2018. Separately, in November 2022, IceCube reported evidence for neutrino emission from **NGC 1068**, an active galaxy about 46 million light-years away.
- These findings confirm that **active galactic nuclei with central black holes** are among the high-energy particle factories that generate cosmic rays, closing a century-long debate about at least one class of sources.
- IceCube scientists continue correlating neutrino-catching events with data from other telescopes — gravitational wave detectors, gamma-ray observatories — as part of the broader **multi-messenger astrophysics** programme.

HIGH-YIELD FACTS

- **Nobel laureate** — Francis Halzen, Belgian-American physicist, awarded Nobel Prize in Physics for 2026
- **Observatory location** — IceCube Neutrino Observatory, Antarctica (South Pole)
- **Construction completed** — 2011, after seven years of construction
- **Sensor count** — 5,160 optical sensors on 86 cables
- **Depth range** — 1.4 km to 2.4 km underground in Antarctic ice
- **Detection volume** — Approximately one cubic kilometre of ice
- **Core concept developed** — Halzen and John G. Learned proposed using ice as a neutrino detector in 1987–1988
- **First landmark detection** — 2013 — two neutrinos at ~140× LHC proton energy, first confirmed extragalactic high-energy neutrino population

VALUE ADDITION

DATA YOU CAN QUOTE

Energy of first landmark neutrinos vs LHC proton — ~140 times LHC proton energy, detected 2013

Distance to NGC 1068 neutrino source — About 46 million light-years; evidence for neutrino emission reported in November 2022

REPORTS, BODIES AND INSTRUMENTS

U.S. National Science Foundation — primary funder and oversight body for IceCube

EXAMPLES FOR THE ANSWER

Multi-messenger astronomy — IceCube's neutrino alerts are combined with LIGO gravitational-wave and gamma-ray telescope data; the 2017 neutron-star merger GW170817 showed how different messengers together reveal what no single instrument can, illustrating the value of complementary observatories.

Cherenkov radiation as a detection principle is also used in proton therapy quality assurance and in water-based neutrino detectors such as Super-Kamiokande (Japan), showing the same physical phenomenon underpins multiple generations of particle detectors across different media.

6. World's First Working Nuclear Clocks: Thorium-229

GS-III · Prelims + Mains · Nuclear clock thorium-229 breakthrough · The Hindu

Syllabus — Science and Technology- developments and their applications and effects in everyday life

Prelims — Science and Technology — nuclear physics, precision timekeeping



Scientists report world's first working nuclear clocks

Vasudevan Mukunth

Atomic clocks are the world's gold standard for timekeeping, at the heart of everything from GPS navigation to synchronised networks. A ytterbium atomic clock is so precise it misses one second every 23 billion years.

Yet scientists are interested in more precise clocks to detect infinitesimal changes in fundamental forces and further advance navigation.

In two papers in *Nature*, scientists from Europe and China have now reported the world's first working nuclear clocks.

In an atomic clock, an atom's electrons are easily disturbed by electric or magnetic fields and temperature changes in a room, but the nucleus is shielded by the electron cloud. Exciting a nucleus usually requires energetic X-rays or gamma rays, which are difficult to harness. However, the thorium-229 isotope's nucleus has a transition energy low enough to be triggered by an ultraviolet laser.

A laser's electric field oscillates rapidly: positive, zero, negative, zero, positive, and so on.

The laser's frequency can drift slightly, however. In a nuclear clock, scientists expose thorium-229 nuclei to the laser and check how readily they become excited. If it happens less often than expected, the laser's frequency has drifted away and a computer corrects it.

In one study, teams from Beijing and Shanghai embedded thorium-229 in calcium fluoride crystals and fired an ultraviolet laser at them. A feedback loop constantly checked the laser against the thorium nuclei and corrected it.

The second effort, by teams from Austria and Germany, built a thorium-229 clock and used it to look for dark matter.

The thorium 229 nucleus has such low transition energy because the strong nuclear force and the electromagnetic force nearly cancel each other out. Thus, the nuclear clock is highly sensitive to any slight changes in these fundamental forces.

Some theories suggest ultralight dark matter may cause these constants to fluctuate as it passes through earth. The team ran the nuclear clock alongside a ytterbium atomic clock. Because the two clocks react differently to fluctuating physics constants, any change in their relative tick rates could reveal the presence of dark matter. The teams didn't find a signal, however.

These prototypes are not yet as precise as the best atomic clocks but their architecture is proven. With upgrades to laser power and crystal quality, scientists expect nuclear clocks to eventually surpass their atomic predecessors.

WHY IN NEWS

Two separate research teams — one from Austria and Germany, another from Beijing and Shanghai — published back-to-back papers in Nature reporting the world's first functional nuclear clocks using thorium-229. The achievement, long theorised, marks a step-change in precision timekeeping and opens a new experimental window on dark matter and fundamental forces.

Why Atomic Clocks Have a Ceiling

- **Atomic clocks** use the oscillations of an atom's electrons as a timekeeping reference; a ytterbium atomic clock misses one second only every 23 billion years.
- Electrons sit in the **outer shell**, where they are vulnerable to electric and magnetic fields and temperature fluctuations in the environment, introducing drift.
- The **nucleus** is shielded by the surrounding electron cloud, making it far more stable — but exciting a nucleus normally requires energetic X-rays or gamma rays, which are impractical to harness in a laboratory clock.

What Makes Thorium-229 the Exception

- The **thorium-229 isotope** possesses an unusually low nuclear transition energy — low enough to be triggered by an **ultraviolet laser**, unlike any other known nucleus.
- This low energy arises because the **strong nuclear force** and the **electromagnetic force** nearly cancel each other out in Th-229, producing a transition energy accessible to optical lasers.
- A laser's electric field oscillates rapidly (positive → zero → negative → zero); if the nucleus absorbs this energy **less often than expected**, the laser's frequency has drifted, and a feedback loop corrects it — the core timekeeping mechanism.

- Because the nucleus is **insensitive to environmental electromagnetic noise**, a nuclear clock promises stability beyond what electron-based atomic clocks can achieve.

Two Independent Experiments That Succeeded

- A **Beijing–Shanghai team** embedded thorium-229 nuclei in **calcium fluoride crystals** and fired an ultraviolet laser at them; a feedback loop continuously checked the laser against the nuclei and corrected any drift.
- An **Austria–Germany team** built a thorium-229 clock and ran it **alongside a ytterbium atomic clock**, using the comparison to search for signatures of dark matter.
- Both teams published in **Nature**, independently confirming that a nuclear clock architecture is experimentally viable.
- The Austria–Germany study specifically tested whether **ultralight dark matter** causes the fundamental constants to fluctuate as it passes through Earth — the nuclear clock's extreme sensitivity to changes in the strong and electromagnetic forces makes it an ideal detector for such effects; **no signal was found** in this first run.

What the Prototypes Can and Cannot Yet Do

- Current prototypes are **not yet as precise** as the best existing atomic clocks; laser power and crystal quality are the binding constraints.
- With improvements to both, scientists expect nuclear clocks to **surpass atomic clocks** in accuracy.
- Because the two clock types respond differently to fluctuating physics constants, **comparing their tick rates** could reveal the presence of dark matter — making nuclear clocks both a timekeeping and a fundamental-physics instrument.
- Applications extend to **GPS navigation**, synchronised networks, and any system where sub-nanosecond timing precision matters at civilisational scale.

HIGH-YIELD FACTS

- **Isotope used** — Thorium-229 (Th-229)
- **Key property** — Only known nucleus with a transition energy low enough to be excited by an ultraviolet laser
- **Publication venue** — Nature (two separate papers)
- **Host material (China study)** — Calcium fluoride crystals
- **Comparison clock (Europe study)** — Ytterbium atomic clock
- **Ytterbium clock accuracy** — Loses one second every 23 billion years
- **Research teams** — One from Austria and Germany; one from Beijing and Shanghai
- **Dark matter type probed** — Ultralight dark matter causing oscillations in fundamental constants

VALUE ADDITION

EXAMPLES FOR THE ANSWER

The GPS satellite network relies on atomic clock precision to within nanoseconds; any drift in the reference oscillator compounds into kilometre-scale positioning errors on the ground — illustrating why gains in clock accuracy have direct strategic and civilian value beyond pure physics.

The 1967 redefinition of the SI second in terms of caesium-133 hyperfine transitions set the precedent that a more stable quantum oscillator can replace the previous timekeeping standard; the nuclear clock represents a potential third such redefinition, useful for answering questions about standards evolution.

The Eötvös experiment (1889) and its successors used comparative measurements of two physical systems to test whether fundamental constants vary — the same logic now applied in nuclear-vs-atomic clock comparisons to search for dark matter, illustrating how precision measurement instruments double as fundamental-physics probes.

7. AI Data Centres Straining India's Power Transmission Grid

GS-III · Prelims + Mains · AI data centres and grid stress · The Hindu

Syllabus — Infrastructure: Energy, Ports, Roads, Airports, Railways etc.

Prelims — General Science and Technology; Indian Economy — infrastructure



AI data-centre boom puts power grid under pressure

Electricity officials across India are grappling with the many ways Artificial Intelligence infrastructure is reshaping power transmission dynamics: AI data centres consume substantially more power than conventional facilities., their demand patterns can also fluctuate sharply, depending on usage, especially LLMs; investments would ultimately be recovered through transmission charges

Aroon Deep
Saptaparno Ghosh
NEW DELHI

In July, the North Eastern Regional Power Committee (NERPC) convened a special meeting with grid operators and Power Grid Corporation of India Ltd. (PGCIL) to address an urgent issue: maintenance contracts for the region's integrated electricity grid were nearing expiry, necessitating discussions on upgrading the systems.

The financial implications were significant. PGCIL informed the meeting that the estimated cost of upgrading the Supervisory Control and Data Acquisition/Energy Management System (SCADA/EMS) at the region's State Load Despatch Centres had risen from ₹521 crore to about ₹688 crore. The reason: AI-driven demand was making hardware used in supervisory systems more expensive.

Escalating costs are not new to the power sector. As manufacturers phase out older components and specialists capable of maintaining legacy systems become harder to find, replacement and maintenance costs can rise sharply. However, the rapid expansion of data-centre projects is adding a new layer of pressure on power generation and transmission infrastructure.

NERPC is not the only regional body grappling with the implications of AI-driven electricity demand.

At a meeting of the Eastern Regional Power Committee's Technical Coordination Committee last December, an Odisha representative flagged the potential "ramping impact" on States when industries such as data centres undertake "bulk collective purchase" of electricity.

High voltage: AI-driven demand is making hardware used in supervisory systems more expensive. REUTERS

Such fluctuations can strain slow-ramping generators, which cannot adjust output quickly enough to match sudden changes in demand. This could expose generators to penalties under the Deviation Settlement Mechanism (DSM) for deviations beyond their control.

At data centres consume substantially more power than conventional facilities. Their demand patterns can also fluctuate sharply, depending on usage, especially LLMs, server distribution and the time zones of their customers.

The issue reached the Central Electricity Authority's National Power Committee in February. Minutes of its meeting noted that "data centres typically exhibit high constant loads, with possible ramping characteristics depending on global time zones and server distribution".

A committee constituted by Grid-India was tasked with studying data centre electricity demand patterns, media reports suggest.

"An incremental demand from data centres ranging between one and two gigawatts per year will not make a huge difference," Alok Kumar, Director General of the All-India Discoms Association (AIDA) said, adding that "[no-recover], this would be concentrated in certain cities only, like in Hyderabad, Mumbai, Chennai, Visakhapatnam and the Delhi NCR region, among others." However, the final leg of electricity transmission could pose a challenge. State transmission utilities would need to expand capacity quickly in locations witnessing a concentration of data-centre projects.

At meetings of the Northern Regional Power Committee's Operation Coordination Sub-Committee last year, officials repeatedly discussed monitoring data centres' compliance with grid-connection requirements before supplying them with electricity.

Mr. Kumar said the cost of upgrades should not become a broader financial burden, as transmission investments would ultimately be recovered through transmission charges.

WHY IN NEWS

In July, the North Eastern Regional Power Committee (NERPC) convened an emergency meeting with PGCIL to address grid maintenance and upgrade costs driven by AI data-centre demand. Separately, the Central Electricity Authority's National Power Committee flagged the issue at a February meeting cited in the report, and Grid-India constituted a dedicated committee to study data-centre electricity demand patterns — signalling that the problem has escalated from regional to national concern.

Why AI Data Centres Are Different from Conventional Loads

- **AI data centres** — especially those running Large Language Models (LLMs) — consume substantially more power than conventional data facilities.
- Their demand is **not flat**: it fluctuates sharply with usage patterns, server distribution, and the time zones of their global customers, creating unpredictable load curves.
- This **'ramping impact'** — flagged by an Odisha representative at the Eastern Regional Power Committee's Technical Coordination Committee in December — strains **slow-ramping generators** that cannot adjust output quickly enough to track sudden demand swings.
- When generators cannot match demand changes fast enough, they risk penalties under the **Deviation Settlement Mechanism (DSM)** for deviations beyond their control.
- The Central Electricity Authority noted that data centres exhibit **high constant loads with possible rampings**, depending on global time zones and server distribution.

Pressure Points on the Physical Grid

- **NERPC** convened a special meeting after finding that maintenance contracts for the region's integrated electricity grid were nearing expiry, and that AI-driven demand was making hardware in **SCADA/EMS (Supervisory Control and Data Acquisition / Energy Management Systems)** more expensive.
- Upgrade costs at State Load Despatch Centres in the north-east rose from ₹521 crore to approximately ₹688 crore, a direct financial consequence of the transition.
- **Legacy system maintenance** is compounding the problem: as manufacturers phase out older components, specialists for those systems become harder to find, and replacement and maintenance costs rise sharply.
- **State transmission utilities** face a particular challenge in the final leg of delivery, as data-centre demand concentrates in specific metros — Hyderabad, Mumbai, Chennai, Visakhapatnam, and Delhi NCR — requiring rapid local capacity expansion.
- Data centres are beginning to pursue **'bulk collective purchase'** of electricity, which the All-India Discoms Association (AIDA) warns could further distort demand patterns for distribution companies.

Grid-Code Compliance and the Connection Gateway

- The Northern Regional Power Committee's **Operation Coordination Sub-Committee** repeatedly discussed last year whether data centres are meeting grid-connection requirements before being supplied with electricity.

- There is growing pressure to enforce **compliance monitoring** of data centres against grid-connection norms as a prerequisite for supply — a step that has not yet been systematically applied.
- An incremental demand of **one to two gigawatts per year** from data centres was characterised by the All-India Discoms Association as manageable at the national level, but the **geographic concentration** in a handful of cities is the real stress point.
- **Grid-India** has been tasked with studying data-centre electricity demand patterns, indicating that the issue has been formally escalated to the national load-despatch level.

Who Bears the Cost of Upgrades

- A central tension in the debate is whether the cost of grid upgrades driven by data-centre expansion should fall on **data centre operators, all consumers through transmission charges, or the State**.
- The All-India Discoms Association has argued that upgrade investments **should not become a broader financial burden**, suggesting cost recovery should be targeted rather than socialised.
- However, the existing regulatory framework routes most transmission infrastructure investment recovery through **transmission charges** levied on all users — meaning data-centre-driven upgrades could, by default, be spread across the consumer base.
- The question remains **unresolved at the policy level**, with no national regulatory instrument yet specifically allocating grid-upgrade costs attributable to AI infrastructure.

HIGH-YIELD FACTS

- **NERPC full form** — North Eastern Regional Power Committee — a regional body under the Ministry of Power coordinating grid operations in north-eastern India
- **PGCIL** — Power Grid Corporation of India Ltd. — the central transmission utility responsible for the inter-state transmission system
- **SCADA/EMS** — Supervisory Control and Data Acquisition / Energy Management System — used in State Load Despatch Centres to monitor and control the grid in real time
- **Deviation Settlement Mechanism** — DSM — a regulatory charge/penalty framework under CERC that financially settles deviations of generators and consumers from their scheduled power injection or drawl
- **Grid-India** — Grid Controller of India Ltd. — the national load despatch centre, responsible for integrated operation of the national grid
- **AIDA** — All-India Discoms Association — a body representing electricity distribution companies across India
- **CEA committee** — The Central Electricity Authority's National Power Committee flagged data-centre grid implications at the February meeting cited in the report
- **Cost escalation example** — NERPC State Load Despatch Centre upgrade cost estimate rose from ₹521 crore to ₹688 crore due to AI-driven hardware demands

VALUE ADDITION

DATA YOU CAN QUOTE

Incremental annual data-centre demand (national estimate) — 1–2 GW per year (AIDA estimate cited in the report)

NERPC upgrade cost increase — ₹521 crore to ₹688 crore (as reported)

REPORTS, BODIES AND INSTRUMENTS

Central Electricity Authority National Power Committee — February meeting minutes cited in the report on data-centre grid implications

Deviation Settlement Mechanism — Central Electricity Regulatory Commission (CERC) regulations

EXAMPLES FOR THE ANSWER

The United States' PJM Interconnection has reported that data-centre load growth in Northern Virginia is forcing multi-billion-dollar transmission upgrades, illustrating how geographic concentration of AI infrastructure creates localised grid bottlenecks even in mature power systems — a comparable dynamic to what India faces in its metro clusters.

In November 2021, Ireland's regulator, the Commission for Regulation of Utilities (CRU), introduced additional data-centre connection criteria covering location, dispatchable generation or storage, and demand flexibility. System operators including EirGrid apply the criteria, illustrating how connection policy can address concentrated grid demand.

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