GS Paper I – Geography

Scientists find one reason why northwest India floods more

Scientists reported evidence of two subseasonal weather patterns turning northwestern South Asia, including northwest India, from a semiarid region into a flood-prone one. First, the tropical monsoon intra-seasonal oscillation strengthened and penetrates deeper inland. Second, the mid-latitude oscillation, a wave of air moving along the jet stream, has slowed, keeping rain-producing systems stuck over the region for longer periods. Together, these changing oscillations account for 44% of the observed increase in flood frequency.

New data explain how black holes have 'forbidden masses'

The theory of stars predicts that a dying star can't form a black hole weighing 50 to 130 solar masses, yet gravitational wave observations have detected several black holes in this mass range, puzzling astronomers. By analysing the latest data collected by instruments in Japan, Italy, and the U.S., scientists have now explained this discrepancy as being the result of hierarchical mergers: when two lighter black holes merge to form a heavier one.

GS Paper II – Polity

All States will benefit from proposed delimitation: PM

Modi seeks to address concerns over the exercise for the first time; government intends to provide definitive guarantee in Parliament, Prime Minister says at a campaign rally in poll-bound Kerala

Varghese K. George
THIRUVALLA

States that have stabilised their populations will not lose their Lok Sabha seats, and all States will benefit from a proposed increase in the size of the House, Prime Minister Narendra Modi told an election rally in Kerala on Saturday.

The Centre is planning amendments to the Constitution and relevant laws to redraw the electoral map of the country, with the size of the Lok Sabha and State Assemblies to be increased by half, with a third of the total seats reserved for women, ahead of the 2029 general election. Parliament's Budget Session is reconvening on April 16 to consider these amendments.

Mr. Modi was responding for the first time to concerns that States that have stabilised their populations would have their representation in the Lok Sabha reduced after delimitation. The Prime Minister said the government wanted to address these concerns.

Allaying concerns: Prime Minister Narendra Modi with BJP candidates at a roadshow as part of the campaign for the Kerala Assembly election in Thiruvananthapuram on Saturday. NIRMAL HARINDRAN

"There are States – be it Kerala, Tamil Nadu, or others – that have done exemplary work in the field of population control. However, certain individuals are spreading misinformation, claiming that because their population growth has slowed, their parliamentary seat allocation will be reduced. We intend to provide a definitive guarantee regarding this matter in Parliament during this session. We wish to formally seal this assurance through legislation – ensuring that in no State will the number of Lok Sabha seats be reduced," he said.

Mr. Modi, however, did not specify whether he was referring to the absolute number of seats of individual States or their respective proportion.

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GS Paper II – Polity

T.N. CM, Union Minister clash over three-language formula

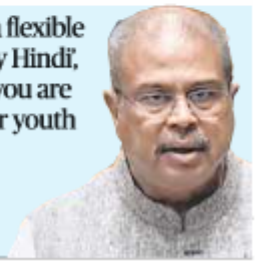
The Hindu Bureau
NEW DELHI

With the Tamil Nadu Assembly election around the corner, the Central Board of Secondary Education (CBSE)'s announcement that it will implement the three-language formula in a phased manner from 2026-27 kicked off a war of words between the DMK government in the State and the BJP-led government at the Centre on "Hindi imposition" versus "progressive and inclusive multilingualism".

Tamil Nadu Chief Minister M.K. Stalin slammed the CBSE's move, which is driven by the National Education Policy, 2020, arguing that it is a "covert" way of "imposing" Hindi on non-Hindi speaking States with no "reciprocity". He demanded that his opponents in the State – the AIADMK and their NDA allies – choose whether they would support the policy, or whether they would, "for once, stand up for the rights, identity, and future of our students".

Union Education Minister Dharmendra Pradhan hit back, saying that this "narrative" was a "tired attempt to mask political failures". He said that "mischaracterising" the policy to portray multilingualism as a threat was "misplaced".

> It is a calculated and deeply concerning attempt at linguistic imposition that vindicates our long-standing apprehensions... This is not commitment; this is rank hypocrisy
>
> **M.K. STALIN**
> Tamil Nadu Chief Minister



> By misrepresenting a flexible policy as 'compulsory Hindi', you are not defending Tamil; you are creating barriers that deny our youth the opportunity to become multilingual global leaders
>
> **DHARMENDRA PRADHAN**
> Union Education Minister

The three-language policy is a "calculated and deeply concerning attempt at linguistic imposition that vindicates our long-standing apprehensions," Mr. Stalin said, adding that it was being advanced "under the guise of promoting 'Indian' languages".

'Stark irony'

Calling out "the stark and unacceptable irony," he said: "The same Union government that has failed to make Tamil a mandatory language in Kendriya Vidyalaya Sangathan schools now seeks to lecture States on promoting Indian languages. This is not commitment; this is rank hypocrisy." "The Centre appears determined to impose Hindi, brushing aside the legitimate, consistent, and democratic concerns raised by Tamil Nadu and several other States," Mr. Stalin said. He called this approach a "direct affront" to the principles of cooperative federalism and an "insult" to the linguistic identity of millions of Indians.

In response, Mr. Pradhan said, "By misrepresenting a flexible policy as 'compulsory Hindi', you are not defending Tamil; you are creating barriers that deny our youth the opportunity to become multilingual global leaders... Tamil is not weakened by the learning of additional languages; it is enriched when its speakers are multilingual, confident, and linguistically empowered."

PLURALITY AGAINST INTENT
» PAGE 8

GS Paper II – Polity

Centre can't treat States as 'subordinates', says Justice Nagarathna

The Hindu Bureau
NEW DELHI

Supreme Court judge, Justice B.V. Nagarathna, on Saturday said the Centre can neither treat States as "subordinates" nor discriminate against the citizens of a State ruled by an opposing political party.

Justice Nagarathna, in line of seniority to be the first woman Chief Justice of India in 2027, said the Centre ought to view the States as coordinates and federalism as a constitutional arrangement of co-equals.

The Supreme Court judge said political differences or conflicting ideologies between the party at the Centre and the party in power in a State should not be a reason to discriminate against the citizens of that State. "Inter-party differences or distinct political ideologies have to be kept aside in the matter of Centre-State relations... The citizens must have the benefit of both governments with regard to the welfare schemes... The citizens of a State cannot be discriminated against in matters of development or in governance," the judge said in her lecture at the Chanakya National Law University on 'Constitutionalism beyond Rights: Why Structure Matters'.

Justice Nagarathna is in line of seniority to be the first woman CJI in 2027. FILE PHOTO

She added, "There cannot be a pick and choose approach vis-à-vis the States when it is in the realm of development programmes for the citizens of a State. Equity as a matter of a fair approach must be adopted."

'Centre as a mentor'

Justice Nagarathna said the Centre and States do not rush to courts as adversaries every time there is a dispute. The Centre has the role of a mentor and a mediator of disputes, while it cannot be seen as an instigator of conflict, she said.

"Issues such as border disputes or water-sharing disputes are too complex, sensitive, and enduring to be reduced to adversarial litigation before the courts alone," the apex court judge said.

GS Paper II – Polity

Sabarimala verdict review: SC notifies 9-judge Bench

Krishnadas Rajagopal
NEW DELHI

The Supreme Court on Saturday notified the nine-judge Bench headed by Chief Justice of India Surya Kant, which is scheduled to hear the Sabarimala review case from April 7.

Besides Chief Justice Kant, the Bench would include Justices B.V. Nagarathna, M.M. Sundresh, Ahsanuddin Amanullah, Aravind Kumar, A.G. Masih, R. Mahadevan, Prasanna B. Varale, and Joymalya Bagchi. The case consists of a series of writ pleas and review petitions based on a 2018 verdict allowing women of menstruating age entry into the Sabarimala Ayyappa temple in Kerala.

A nine-judge Bench would be taking up the case for a substantial hearing on the Constitutional questions involved after a hiatus of over six years.

Priests perform puja at the holy steps of the Sabarimala Ayyappa temple in Kerala. LEJU KAMAL

An earlier nine-judge Bench had been constituted in 2019 by then Chief Justice of India Sharad A. Bobde. The hearings before that Bench had to be aborted abruptly due to the onset of the COVID-19 pandemic. Chief Justice Kant is the only remaining serving judge of the previous nine-judge Bench.

The top court intends to hear and wrap up the case by the end of April. The nine-judge Bench has provided petitioners hearing slots from April 7 to April 9.

Those opposing them would be heard from April 14 to April 16. The rejoinder submissions would be heard on April 21, followed by the concluding submissions from the *amicus curiae* on April 22. Parties have to adhere to the timeline, the court has stressed.

In November 2019, a majority judgment by a five-judge Constitution Bench led by the then Chief Justice of India Ranjan Gogoi had initially referred the Sabarimala review and writ petitions to a seven-judge Bench.

Wider questions of law

But the 2019-majority judgment did not confine the reference to merely the Sabarimala case. It had taken a wider perspective of the questions of law which touched on the ecclesiastical, including whether religious practices considered essential should be given Constitutional protection, and the extent of judicial intervention in such matters. The Gogoi Bench had clubbed the Sabarimala case review with other pending petitions concerning other faiths, but posing similar questions of law.

These included the right of Muslim women to enter mosques; the right of Parsi women who have married out of their faith to enter their religious place of worship, and the issue of female genital mutilation practised by the Dawoodi Bohra community.

Chief Justice Bobde (as he was then) had constituted a nine-judge Bench, instead of a seven-judge Bench, as it was found necessary to examine a 1954 judgment by a seven-judge Bench in the Shirur Mutt case. Any overturning of the Shirur Mutt case, which had for the first time gone into the issue of 'essential religious practice', would require a Bench of larger numerical strength.

A ND-NDE

GS Paper II – Polity

Row over language policy pits plurality concerns against intent

The Hindu Bureau
NEW DELHI

In a heated exchange on Saturday on the CBSE's three-language formula, the Union government emphasised the promotion of Indian languages and policy intent, while Tamil Nadu's leadership raised questions about linguistic equity, administrative readiness, and the broader impact on non-Hindi-speaking States.

Dismissing concerns raised by Tamil Nadu Chief Minister M.K. Stalin, Union Education Minister Dharmendra Pradhan on Saturday said the arguments "ignored ground reality". He claimed that the Union government "actively encourages students across India to embrace Indian languages," even while the Tamil Nadu government "continues to deprive Tamil students of diverse opportunities for the sake of a divisive vote bank."


The CBSE has announced that it will gradually implement the three-language formula.

The arguments continued on X, with DMK leaders including Kanimozhi and P. Wilson supporting Mr. Stalin's arguments on the social media platform, while T.N. BJP leader K. Annamalai backed Mr. Pradhan's argument by asking how the policy imposes Hindi on students.

Mr. Stalin asked if students in Hindi-speaking States would be mandated to learn Tamil, Telugu, Kannada, Malayalam, or even languages like Bengali or Marathi. Calling the policy "ill-conceived," he asked whether the Union government was awake to the ground realities of "teacher availability, training capacity, and infrastructure."

He added: "This is not merely a question of language – it is a question of fairness, federalism, and equal opportunity. By structurally privileging Hindi-speaking students, this policy risks creating entrenched advantages in higher education and employment, further widening regional disparities... India's strength lies in diversity – not in enforced uniformity."

Mr. Pradhan responded, saying, "The talk of resources is merely a facade. It is the DMK government that has stalled the establishment of PM SHRI schools in Tamil Nadu by refusing to sign the MoU after giving an undertaking for the same." He also accused the DMK government of "obstructing" the implementation of Navodaya Vidyalayas in the State, saying this was "prioritising political narratives over educational quality". He asserted that it was because of the DMK's "dishonest politics" that modern infrastructure and teachers had been "effectively withheld", reiterating his government's "commitment" to funding and teacher training.

Mr. Stalin said that Mr. Pradhan's remarks were "deeply irresponsible and reckless, and reflect an entrenched disregard for India's plurality, federal values, and respect for States."

GS Paper II – Polity

What are the concerns over the FCRA Bill?

How does the Home Ministry regulate foreign donations to NGOs in India? What are the key changes proposed to the Foreign Contribution (Regulation) Amendment Bill, 2026? Why has the Opposition objected to the Bill and why was the Bill deferred? What is its current status?

Vijaita Singh

The story so far:

The Central government proposed to introduce the Foreign Contribution (Regulation) Amendment Bill, 2026 during the Budget Session of Parliament, which concluded on April 2. The Bill seeks to amend the Foreign Contribution (Regulation) Act, 2010, under which registration is mandatory for non-governmental organisations (NGOs) and associations to receive foreign funds or donations. It was introduced in the Lok Sabha on March 25; however, following an uproar by Opposition parties, its discussion and passage were deferred.

According to the statement of objects and reasons, around 16,000 associations are registered under the FCRA and receive approximately ₹22,000 crore annually. The Act regulates the acceptance and utilisation of foreign contributions to ensure that such inflows do not adversely affect national interest, public order, or national security.

> The Catholic Bishops' Conference of India said the Bill amounts to executive overreach and that it could unduly interfere with minority institutions and civil society

Opposition MPs demanding the withdrawal of the Foreign Contribution (Regulation) Amendment Bill, 2026, during the Budget Session of Parliament, in New Delhi. ANI

What are the key changes proposed?

One of the key changes proposed in the Bill is the appointment of a 'designated authority' to take over, manage, or dispose of assets created from foreign funds when an NGO's FCRA registration is suspended, cancelled, or not renewed. This authority will have the powers of a civil court and can order the transfer or sale of assets owned by NGOs to either the government or any other body. The 2010 Act provided for regulation of foreign fund flows, but lacked a statutory framework for managing assets created from such funds. The government said that Section 15 of the Act provides for vesting of assets, but the absence of a comprehensive framework for the supervision, management, and disposal of such assets has led to administrative uncertainty and scope for misuse.

Another proposed amendment broadens the definition of an NGO's 'key functionary' beyond office bearers and directors to include trustees, partners, the Karta of a Hindu undivided family, governing body members, or anyone controlling or managing the organisation, and makes them liable for FCRA offences unless they can prove lack of knowledge or due diligence.

What are the other changes proposed?

The Bill seeks to amend Section 43 of the parent Act to require any law enforcement agency or State government to obtain prior approval from the Central government before initiating investigations into FCRA-related complaints.

It also proposes timelines for the receipt and utilisation of foreign contributions under the 'prior permission' category (one-time receipt of funds), and provides for automatic cessation of certificates upon expiry or non-renewal.

The Bill proposes to reduce the maximum imprisonment for FCRA offences from five years to one year. It also proposes fixed timelines for the utilisation of foreign funds received under the 'prior permission' category unlike the open-ended provision under the 2010 Act.

How does the Ministry of Home Affairs (MHA) regulate foreign donations in India?

The MHA regulates foreign donations in the country through the FCRA to ensure that such funds do not adversely affect the country's internal security. The legislation was first enacted in 1976. In 2010, it was repealed and replaced with a new legislation. The 2010 Act came into force on May 1, 2011 and has been amended in 2016, 2018, and 2020.

The FCRA registration is valid for five years, after which the NGO has to apply for a renewal. Since 2015, the FCRA registrations of more than 18,000 NGOs have been cancelled. As on April 3, there are 14,965 FCRA-registered NGOs active in the country. NGOs can receive foreign contributions for social, educational, religious, economic, and cultural programmes.

Why is the Bill being opposed?

The Catholic Bishops' Conference of India said the Bill amounts to "executive overreach" and raises concerns about "undue interference" in the functioning of minority institutions and civil society groups. The body objected to "clauses that grant sweeping powers to the Central government, allowing it to deny renewal or cancel licenses of organisations" and the powers "to assume control over institutions, including their funds, properties, and other assets." The Chief Ministers of poll-bound Tamil Nadu and Kerala have opposed the Bill as well.

What is the status of the Bill?

The Bill was deferred following an uproar by the Opposition. In Kerala and Tamil Nadu, there were fears it could be misused to seize assets of minority institutions, such as churches. Meanwhile, the Bharatiya Janata Party has been reaching out to the Christian community in Kerala to build a support base. The legislation remains active.

A ND-NDE

GS Paper II – International Relations

Why does Trump want to pull out of NATO?

Why does the U.S. administration believe that NATO's founding principles and membership need to be 're-examined'? Why was NATO formed, and what are the recent developments that have led to fissures? Can the U.S. easily exit NATO? How much does it contribute to the alliance?

Suhasini Haidar

The story so far:

Last week, in an interview to the British newspaper, U.S. President Donald Trump said withdrawing U.S. membership from the North Atlantic Treaty Organization (NATO) is now "beyond reconsideration". Through this, he indicated that one of America's oldest alliances since World War 2 could be on the brink of a break-up.

The tough words, and the U.S. President's description of NATO as a "paper tiger", reflect an antagonism that goes back more than a decade that has been heightened during the ongoing war with Iran. Even so, the U.S. may not find it easy to exit the 32-nation, 76-year old alliance.

Why is Mr. Trump angry with NATO?

The immediate trigger for Mr. Trump's comments to *The Telegraph* was that most NATO allies refused U.S. requests for military and airspace support in connection with the war against Iran, where the U.S. has faced significant setbacks in recent weeks.

While Spain and Italy have directly criticised the U.S.-Israeli strikes on Iran, France has denied U.S. military jets overflight permission to fly to Israel. Even the U.S.'s closest allies – the U.K., Germany, and Canada – have refused to take part in operations.

U.S. officials feel that this stand violates Article 5 of the North Atlantic Treaty, which states that "an armed attack against one NATO member shall be considered an attack against them all".

Two days before Mr. Trump's interview appeared, U.S. Secretary of State Marco Rubio had also told an American television channel that NATO's founding principles and membership would have to be "re-examined". "If NATO is just about us (the U.S.) defending Europe if they're attacked, but them denying us basing rights when we need them, then that's not a very good arrangement," Mr. Rubio said.

> As per the North Atlantic Treaty, the U.S. government would have to hand itself the exit notice, and then inform other countries, which would make for an awkward process

NATO Secretary General Mark Rutte during a press conference at the NATO headquarters in Brussels, Belgium, on March 26, 2026. REUTERS

The seeds of U.S. discontent with NATO had been planted by Mr. Trump ever since his first term as President, when he announced that NATO was "obsolete". He criticised European allies for not pulling their weight in military expenditure while depending on the U.S. for their defence. In Mr. Trump's second term, the rift grew over his rough treatment of Ukraine. More recently, he was angered that NATO members criticised the U.S.'s regime change operations in Venezuela and that they fiercely opposed his plans to annexe Greenland. With the U.S.-Israel war with Iran entering its sixth week, and no exit strategy in sight, European allies have become more determined in not joining the operations.

What is the purpose of NATO?

NATO (or OTAN, according to the French abbreviation) was formed in 1949, with the U.S., Canada and 10 West European countries which felt threatened by the Soviet Union, particularly after the installation of pro-Soviet Communist regimes in Eastern Europe and China. The North Atlantic Treaty, signed in Washington DC on April 4, 1949, created the inter-governmental military grouping mandated with "collective security". Over time, NATO gathered more members, including Greece and Turkey in the 1950s and Spain in 1982.

After the collapse of the Soviet Union, more than a dozen East European countries joined, triggering a backlash from Russia. After Russia's 2022 invasion of Ukraine, which was not a member, Finland and Sweden joined NATO, taking the total membership up to 32.

Ironically, although NATO was set up to counter the Soviet threat, NATO forces did not carry out a single military operation during the Cold War; it was only after conflicts in the Baltic states in the 1990s that NATO forces began joint operational missions, such as in Iraq (1990 and 2003), Bosnia (1992), Kosovo (1999), and Afghanistan (2001).

NATO does not have a separate independent force, but when required, combines resources and personnel of the 32 members that operate under a unified command structure called the Supreme Headquarters Allied Powers Europe (SHAPE), based in Belgium. It is led by the Supreme Allied Commander Europe, a U.S. 4-star General or Admiral who heads the U.S. European Command.

Although Ukraine has now backed away from plans to join NATO, Ukrainian forces have worked closely with NATO after Russia launched its 'Special Military Operations' in February 2022. They have received major aid packages, including a $40 billion pledge at the NATO Summit in 2024, training, and security assistance.

As a result, Mr. Trump has complained that when it came to his demands that NATO members support U.S. operations in Iran, send their navies to help open up the Strait of Hormuz, or facilitate refuelling and overflight missions, their response should have been "automatic".

"We've been there automatically, including Ukraine," he said. "Ukraine wasn't our problem. It was a test, and we were there for them, and we would always have been there for them. They weren't there for us," he told *The Telegraph*.

How much does the U.S. fund NATO operations?

Throughout all these operations, the U.S. has provided much of NATO's funding, including 62% of the defence spending and about 15% of the civil budget of the alliance. It also provides NATO countries with a "nuclear umbrella" and maintains U.S. military bases that enhance deterrence in the region. Under increasing security concerns and U.S. pressure, all NATO members agreed at the 2025 Hague Summit to raise defence spending to 5% of their GDP by 2035, but Mr. Trump has continued to chide allies to share more of the burden.

How hard would it be for the U.S. to pull out of NATO?

A U.S. exit from NATO or the Alliance Treaty seems unimaginable and is many times more difficult than its exit from more than 60 different multilateral organisations and treaties, including the World Health Organization and the United Nations Framework Convention on Climate Change in January 2026, and much more legally complex than the U.K.'s exit from the European Union (Brexit) in January 2020.

Article 13 of the North Atlantic Treaty provides for the withdrawal of any member, but says the member must submit a one-year "notice of denunciation... to the Government of the United States of America, which will inform the Governments of the other Parties." As the depository authority, the U.S. government would therefore have to hand itself the notice, and then inform other countries, which would make for an awkward process.

In addition, and as a measure against Mr. Trump's own statements in his first tenure, the Biden administration pushed a law through the U.S. Congress in 2023 that prohibits the U.S. President from trying to "suspend, terminate, denounce, or withdraw the United States from the North Atlantic Treaty – without the advice and consent of the Senate or an act of Congress". Alternative paths could see the U.S. withdraw personnel from SHAPE or skip NATO meetings – in the manner India has withdrawn from attending SAARC summits – which would make the organisation virtually defunct.

In terms of its impact on the world order, especially in the midst of a war, the U.S.' withdrawal from NATO would lead to the remaking of all global security structures, severely weaken the hold of the Western coalition, and strengthen other global powers such as Russia and China. It is therefore more likely that both the U.S. and its NATO allies will work to avoid such a drastic step, beginning with the visit of NATO Secretary General Mark Rutte to Washington on April 8.

GS Paper III – Science & Technology

ISRO to test astronaut capability in a high altitude environment

Press Trust of India
NEW DELHI

The Indian Space Research Organisation (ISRO) has announced the launch of a mission in Ladakh to examine the physiological, psychological and operational dynamics of astronauts and ground teams functioning in a high-altitude environment.

Known as Mission MITRA (Mapping of Interoperable Traits and Response Assessment), the study will be conducted until April 9 at an altitude of approximately 3,500 metres in Leh, simulating the environmental conditions of hypoxia, low temperature and isolation as a natural analog for spaceflight operations.

"This study is targeted to generate vital understanding on the team interoperability between crew and ground control teams and effectiveness of decision making under environmental and operational stress," the ISRO said in a statement on April 3. "Analog missions conducted under controlled yet realistic conditions are utilised to understand how crew performs under challenging conditions."

Astronauts will be kept in challenging conditions. PTI

GS Paper III – Science & Technology

Nuclear fusion cost models too optimistic to be viable: experts

Vasudevan Mukunth

Researchers and investors worldwide are currently pouring billions of dollars into nuclear fusion in the hopes that it will prove to be a reliable source of green power. These investments often bank on economic models that assume the cost of the underlying technologies will drop rapidly as the industry expands. However, researchers have published an analysis in *Nature Energy* concluding that these projections are based on arbitrary numbers rather than hard evidence.

The authors, from ETH Zürich in Switzerland, have added that if investors continue to use over-optimistic forecasts, they risk misallocating vital funds that can be routed to other, more fruitful climate mitigation plans.

The team's analysis focuses on the percentage by which a technology's cost drops every time its global capacity doubles – a factor called the experience rate. Solar panels and batteries have high experience rates, so their prices have plummeted in the last decade. Current nuclear fusion models often assume experience rates between 8% and 20%. After interviewing 28 experts in magnetic fusion and laser-based inertial fusion technologies, the researchers found that these figures are likely too high.

Fusion plants are bound to be large, with experts estimating even the smallest viable facilities having to produce hundreds of megawatts to overcome the energy requirements of their own cooling and heating systems.

Nuclear fusion is also extraordinarily complex, with experts rating design complexity as being equal to or even exceeding nuclear fission. One expert described a traditional fission reactor as "trivial" compared to a fusion reactor. Magnetic fusion devices also use an onion-like structure where changing even one component requires redesigning the whole system, making it difficult to streamline manufacturing. Fusion plants also have to be tailored to the local seismic risk, access to cooling water, and the regulatory regime, preventing mass production.

Taken together, the researchers estimated that fusion power's experience rate is closer to fission power's historical rate, around 2%. Because the technology's capital costs are also high, a low experience rate foretells a significant challenge to becoming price-competitive with solar or even advanced fission.

The researchers instead urge the research community to consider alternative designs, such as those using different fuels or smaller reactor configurations, which could offer the potential for better cost reductions.

GS Paper III – Science & Technology

'Cloning' hurdle skirted to perfectly copy quantum state

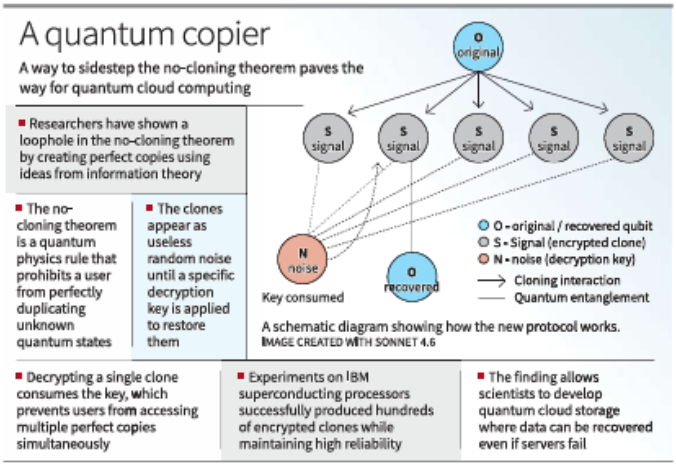
The no-cloning theorem is a quantum physics rule that prohibits a user from perfectly duplicating unknown quantum states; researchers have reported a way around it that could pave the way for technologies like quantum cloud storage

S. Srinivasan
Vasudevan Mukunth

Quantum physics has a rule called the no-cloning theorem that prevents you from making a perfect copy of an unknown quantum state. It has shaped everything from quantum cryptography to quantum computing, and researchers have largely accepted it as an inalienable constraint.

Copying data in classical computing is trivial. We routinely copy files to the cloud for backup and make copies of code to share it. Quantum computers, however, cannot do any of this in the obvious way because of the no-cloning theorem, which is thus a serious obstacle to building robust quantum infrastructure.

But recently, a team of physicists from Japan, Canada, Germany, and IBM Quantum experimentally demonstrated a loophole in the theorem, showing that quantum information can indeed be duplicated provided the clones remain encrypted.



A key for noise

Previous researchers had developed approximate methods that produced imperfect copies with about 83% fidelity, the proven maximum for these approaches. But these copies were noisy and impractical.

In 2023, Koji Yamaguchi and Achim Kempf – two of the new paper's authors – reported the loophole (published in *Physical Review Letters* on January 6 this year). Rather than accepting degraded copies, they proved (on paper) that it is possible to create perfect ones as long as each copy is scrambled by quantum noise so that it is individually useless.

This noise is not random. It is recorded in a set of 'noise qubits' that serves as the decryption key. To create clones, the original qubit is allowed to interact with a series of signal qubits, called the quantum register, in a way that spreads the information across signal qubits. At this stage, each new qubit is a clone but also a maximally mixed state, meaning it looks like random noise to an observer.

When you want to recover the original state, you apply the decryption operation to any one of the encrypted clones using the full set of noise qubits. This restores the original perfectly. But the decryption process consumes the key. So after you decrypt one clone, the key is gone and every remaining clone becomes permanently scrambled. Which means you only get one perfect recovery. (The no-cloning theorem says you cannot freely access multiple identical copies.)

Four tests

To test this idea, the team ran experiments directly on the IBM Heron R2 superconducting processors, which feature 156 physical qubits, using up to 154 qubits across four experiments.

The first experiment measured how fidelity – how close the recovered state is to the original state – decayed as the number of encrypted clones grew from 2 to 15. The team found that making more copies did not make each copy harder to recover. The second test confirmed that the clones were quantum rather than classical.

The third was the most ambitious. Instead of creating all clones in a single step, the team cloned one qubit, then cloned those clones, and so on.

Using all 154 available qubits, the researchers found that with more qubits with equal levels of noise, up to 729 clones could be produced while keeping the signal detectable.

Finally, the team applied the protocol in parallel across multiple qubits simultaneously entangled in a GHZ state – a complex form of entanglement involving many qubits. And they confirmed that they could use encrypted cloning to back up entire quantum registers rather than just single isolated qubits.

According to the authors of the study, their experiments require scientists to refine the understanding of the no-cloning theorem. They argued that the real constraint is not that quantum information cannot be copied and spread widely – it can – but that the access to that information is restricted and that each setup allows only one shot at retrieving it.

Rare instance

"For example, encrypted cloning enables... redundant quantum cloud storage: a quantum cloud storage provider hosts encrypted clones of a client's quantum data on separate servers," the authors wrote. "As long as at least one of the servers survives, the client can recover all of their data perfectly by decrypting the surviving clones. Quantum cloud storage could serve as a platform also for quantum cloud computing."

This is a rare instance in which a new, profound idea has been tested almost immediately, and the initial results prove that the protocol performs as expected.

A key advantage of this protocol over many earlier proposals is that the recovered qubit is identical to the original state rather than an approximate copy. The work is sure to stimulate further research on building reliable quantum memories, which are essential for many quantum information processing protocols.

(S. Srinivasan is a professor of physics at Krea University)

GS Paper III – Science & Technology

Speeding up enzyme reactions in microbes using light

SPEAKING OF SCIENCE

D. Balasubramanian

We know photosynthesis is a feature of plants which absorb sunlight and use the energy to convert atmospheric CO_2 into glucose. While sunlight peaks in the 400-700 nm region (of wavelengths), scientists have shone ultraviolet radiation (well below 400 nm) on plants and found that this opens new avenues in enzyme engineering and drugs through photocatalysis – the process of using light to jumpstart chemical reactions.

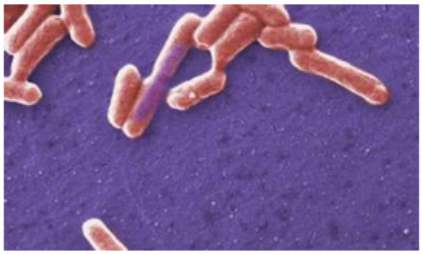
Light-activated enzymes turn light energy into chemical action. In some cases, light triggers lightning-fast shape changes that turn on the enzyme. These movements can now be tracked in real-time on a scale of trillionths of a second using ultra-fast imaging.

Researchers at Nanjing University, China, have used visible light to trigger inherent enzymes as catalysts, paving the way for manufacturing useful products and drugs. This technology, called 'photobiocatalysis', repurposes natural enzymes to produce novel products of medicinal value (*Organic Chemistry Frontiers*, 12 (16), April 2025, pages).

Photobiocatalysis pairs the energy of light with the precision engineering of enzymes, allowing scientists to assemble very complex structures.

Use of microbes

Some plants have been found to contain an alkaloid called securinine. The genes that make this alkaloid resemble bacterial genes and have been borrowed from bacteria that invade plants. This discovery has allowed scientists to look for more such repurposed genes in plants and find new paths for drug discovery. These use the molecules offered by microbes in order to produce new defence molecules that are toxic.



Antaya University, Türkiye, researchers have used *E. coli* bacteria as a versatile factory to produce useful compounds. PUBLIC DOMAIN

Taking a cue from this transfer of genes seen in nature, scientists have engineered the yeast *Pichia pastoris*, which is found in the soil, to help produce two plant-derived anti-cancer drugs called vinblastine and vincristine (*Nature Synthesis*, 2, 231-242, 2023). These alkaloids, found in the periwinkle plant, are very complex molecules that are put together by the coordinated action of 30 enzymes.

There is also increasing use of intact organisms like mice or zebrafish, and even the bacterial workhorse *Escherichia coli* to produce novel chemicals of use in agriculture or medicine.

Driven by light

İbrahim İncir and Özlem Kaplan from the genetics and bioengineering faculty of Antaya University, Türkiye, have shown that *E. coli* is a versatile cell factory, which has been used to produce novel and useful products such as insulin and other cost-effective proteins of medical interest. Scientists at Kobe University, Japan have similarly used *E. coli* to produce pyridine dicarboxylate, a degradable plastic (*Nature Chemical Biology* 21, 1171-1181 (2025)).

And researchers from DuPont, Wilmington, Delaware have used *E. coli* to convert glucose to an industrial styrene polymer (*Metabolic Engineering* vol. 9, issue 3, May 2007). Likewise, Ajikumaran et al. from the Massachusetts Institute of Technology in the U.S. have used *E. coli* to synthesise the precursor of the anti-cancer drug Taxol.

The most recent application of combining photobiosynthesis with a microbial 'bioreactor' has come from the group of Huimin Zhao at the University of Illinois, Urbana-Champaign, who have engineered *E. coli* to produce non-natural olefins and reductases directly from glucose using enzymes activated by blue light. Using *E. coli* allows scientists to scale the process up for large scale production, where they combine biosynthesis with photo-biotechnology (*Nature Catalysis* vol. 9, January 2026, pages 62-72). They also point out that this approach has the potential for large-scale chemical production where reactions driven by light are integrated into cellular metabolism.

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