# Vacuum Birefringence

***Prelims:*** *Current events of national and international importance | Space*

## Why in News?

*In Aug 2026, scientists reported evidence that vacuum near a super-magnetic star behaves like a crystal, altering light travel and supporting quantum predictions that space is not truly empty.*

## Is space really empty?

- According to classical physics, a vacuum is defined as complete nothingness.
- In contrast, **quantum electrodynamics (QED**) offers a different perspective.
    - So-called empty space is permeated by **virtual particle pairs, such as electron-positron pairs,** which continuously appear and vanish.
    - Under typical conditions, these virtual particles exert negligible influence on the propagation of light.

| **Heisenberg and Euler Theory** |
| --- |
| • In the 1930s, **Heisenberg and Euler** made a significant prediction regarding this phenomenon:<br>• They proposed that, within an **extremely strong magnetic field**, the quantum vacuum would behave analogously to a crystal, thereby altering the transmission of light.<br>• This phenomenon is known as **vacuum birefringence**. |

- **Vacuum birefringence –** It is a phenomenon predicted by quantum electrodynamics (QED), in which an extremely strong magnetic field causes the quantum vacuum to behave similarly to a birefringent crystal.
- **Meaning –**"bi-" denotes two & “Refringence” means “refraction”.
- A birefringent material alters the behaviour of light depending on the direction of its polarisation.
- A calcite crystal is a classic example of a birefringent material.
- Quantum electrodynamics predicts that, under an extremely strong magnetic field, the vacuum itself can exhibit a similar birefringent effect.
- **Instruments Utilized**
    - IXPE (Imaging X-ray Polarimetry Explorer) was employed to measure X-ray polarisation.
    - NICER, located on the International Space Station, was used for X-ray timing and spectral analysis.
    - Murriyang (Parkes radio telescope) conducted radio polarimetry to map the magnetic geometry.

- **Recent study** - The target of this study is magnetar 1E 1547.0−5408, located approximately 14,700 light-years away and classified as a rare radio-emitting magnetar.
- **Observations –** X-ray linear polarisation degree (PD) from the magnetar reached ~65–80%, far higher than in typical X-ray sources.
- PD decreased with increasing X-ray energy, matching QED predictions for vacuum birefringence.
- The polarisation angle behaviour also fit models where X-rays travel through a strongly magnetised quantum vacuum.
- **Interpretation –** Models including vacuum birefringence fit the data much better than those without it.

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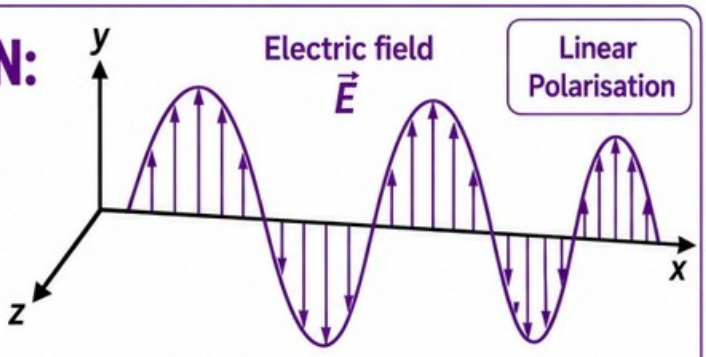
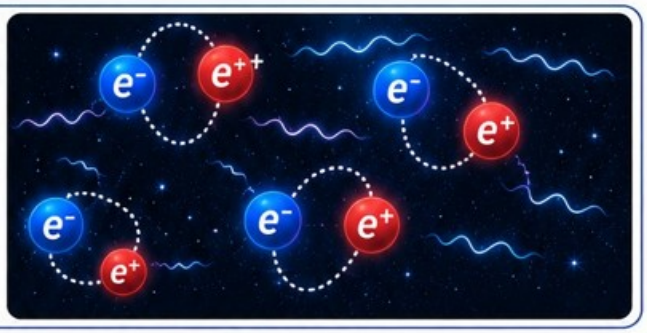
## 01 POLARISATION:

Polarisation refers to the orientation of the electric field vector in an electromagnetic wave. Linear polarisation indicates a specific, preferred direction.




## 02 QUANTUM VACUUM:

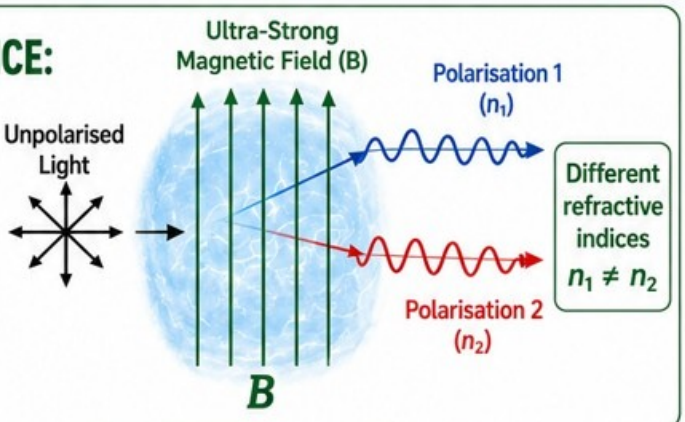
The quantum vacuum is the ground state of quantum fields. It is not empty; rather, it is filled with virtual particle-antiparticle pairs.




## 03 VACUUM BIREFRINGENCE:

Vacuum birefringence is a quantum electrodynamics (QED) phenomenon in which an ultra-strong magnetic field causes the vacuum to behave like a birefringent crystal.

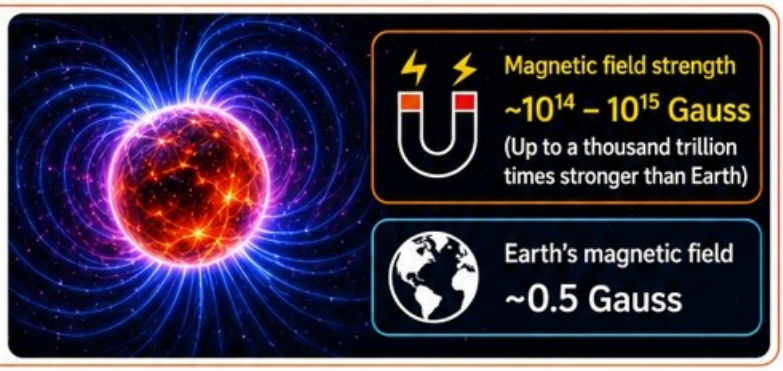
This effect results in different refractive indices for various light polarisations, leading to significant polarisation of transmitted light.




## 04 MAGNETAR:

A magnetar is a rare type of neutron star characterized by an extraordinarily powerful magnetic field, which can be up to a thousand trillion times stronger than that of Earth.

It is capable of generating the conditions necessary for vacuum birefringence.




**Reference**

[The Hindu | Space is Not Empty]

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