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NEUTRINOS: AVANT-GARDE PARTICLES THAT SOLVE THE MYSTERY OF THE COSMOS

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Abstract:

Neutrino is an obscure particle with no mass and charge that makes up the universe. Unlike electrons and photons, neutrinos can penetrate deep surfaces and travel through space without being affected by interstellar magnetic fields or intervening matter. Though we are bombarded by 650 trillion particles per second, it took scientists decades to prove its existence. Neutrinos have the potential to speed up global communication as they can pass through any medium without interference. Encryption of messages in neutrinos is also possible. The IceCube lab in Antarctica has built a neutrino detector that has sensed high-energy neutrinos produced by black holes and violent star deaths. Thus neutrinos serve as the missing link in finding dark matter. Uncovering mineral deposits, finding geological defects and early detection of disasters are other possible scopes.

Key Words: Neutrino, Nuclear Fusion & Muons

Introduction:

It all started as a maddening little problem with Beta Radioactive decay wherein a parent nucleus emits an electron and changes from one element to another. But what happened is that the energy of the parent nucleus was not equal to the sum of the energy of electron and daughter nucleus, some amount of energy was missing. Conservation of energy law that was dear held for centuries seemed to be broken. Wolfgang Pauli in 1930, observed that unobserved particles called Neutrino were emitted. Neutrinos are similar to the more familiar electron, with one crucial difference: neutrinos do not carry electric charge. Even though we are bombarded by 650 trillion of them every second, it took years to prove them. These Neutrinos do not interact with strong forces or electromagnetic forces; they interact only with weak forces and gravity.

Detection:

Neutrinos are notoriously elusive particles. To detect their presence in order to prove Pauli's prediction right was a Herculean task. One idea was to place a neutrino detector near a nuclear detonator. That idea was quickly nixed as it was dismissed as being destructive. Neutrinos were later detected in a nuclear reactor. The research is underway and recently it has been discovered being emitted from distant supernovae and radioactive material inside the earth.

Neutrino Flavours:

Three types of neutrinos are known; there is strong evidence that no additional neutrinos exist, unless their properties are unexpectedly very different from the known types. Each type or "flavour" of neutrino is related to a charged particle (which gives the corresponding neutrino its name). Hence, the "electron neutrino" is associated with the electron, and two other neutrinos are associated with heavier versions of the electron called the muon and the tau.

Homestake Experiment:

Chemist Dr. Raymond Davis in the late 1960's performed the Homestake experiment. The experiment took place in the Homestake Gold Mine in Lead, South Dakota. Davis placed 1,478 meters (4,850 feet) underground a 380 cubic meter (100,000 gallon) tank of perchloroethylene, a common dry-cleaning fluid. A big target deep underground was needed to prevent interference from cosmic rays, taking into account the very small probability of a successful neutrino capture, and, therefore, very low effect rate even with the huge mass of the target. Perchloroethylene was chosen because it is rich in chlorine. Upon interaction with an electron neutrino, a chlorine-37 atom transforms into a radioactive isotope of argon-37, which can then be extracted and counted. The reaction of neutrino capture is

$$\nu_e + {}^{37}\mathrm{Cl} \longrightarrow {}^{37}\mathrm{Ar} + e^-.$$

The reaction threshold is 0.814 MeV, i.e. the neutrino should have at least this energy to be captured by the chlorine-37 nucleus.

Every few weeks, Davis bubbled helium through the tank to collect the argon that had formed. A small (few cubic cm) gas counter was filled by the collected few tens of atoms of argon-37 (together with the stable argon) to detect its decays. In such a way, Davis was able to determine how many neutrinos had been captured. Every week of operation he checked the vat. Of the ten argon atoms that he had expected to find, he found only three. This was called the Solar Neutrino Deficit.

Solar Neutrino Deficit:

Many subsequent radiochemical and water Cherenkov detectors confirmed the deficit, but neutrino oscillation was not conclusively identified as the source of the deficit until the Sudbury Neutrino Observatory provided clear evidence of neutrino flavour change in 2001. Neutrinos oscillate into different flavours. Takaaki Kajita and Arthur McDonald were awarded a Nobel Prize for the discovery of neutrino oscillations, which in turn shows that neutrinos have mass.

Applications:

Though these ghost particles are highly unstable, their applications are multifold. Their speed, resistance to matter and inert nature make them resourceful. Here are a few examples:

- ✓ **Communication with Submarines:** At present, electromagnetic radiations are the preferred choice for communication as they can be transmitted easily. However, they are shielded by seawater making them impotent towards submarine communication. For this reason, submarines have to float around with a wired antenna sticking up from the surface of water that constrains its speed. Neutrinos on the other hand can travel light years of lead without being affected, so an ocean would pose no problem. Neutrinos can offer data rates greater than 100 bits per second. That's three orders of magnitude better than ELF communication. They can be produced by accelerating muon particles, which then decay to produce neutrinos. The detection of neutrinos is just the reverse wherein they interact with matter to produce muons that can be detected relatively easily. Patrick Huber, a physicist at Virginia Tech, covered the hull of a submarine with muon detector modules. By noting the point of entry and exit, he successfully computed the position of the submarine. Cherenkov pattern is another wonderful method by which the position of the submarine can be reconstructed. The only drawback is that messages can only be sent but not received.

- ✓ **Global communication:** Communication is largely done over the earth rather than through it. That is, messages are sent, received and amplified by a satellite and then sent to ground equipment. Thus the time for traversing is long. Communication can be made faster by using neutrinos to send messages. Scientists have proven that it's possible to encode a message in neutrinos using binary code. This was then used to modulate the neutrino beam with a bit rate of 0.1 bits/s. The message was received with a bit error rate of just 1%, allowing the message to be decoded easily after one repetition.

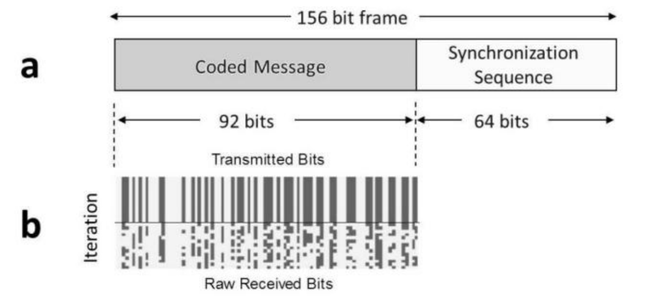

Fig. 5. Format and representations of transmitted data. (a) Frame structure of the transmission. (b) Depictions of the transmitted and received data.

- ✓ **Nuclear Proliferation:** The International Atomic Energy Agency (IAEA) monitors countries across the globe to check for illicit nuclear proliferation. All nuclear reactors emit radiation and neutrinos. While radiation can be blocked with a few feet of soil or concrete, neutrinos pass unimpeded through hundreds of miles of solid Earth. Giant neutrino detectors could be built by the IAEA within the borders of a country to keep tabs on the reactors of a nearby nation hostile to inspections. Based on the detected neutrino signature, monitors can discern what is happening inside of that nation's reactors.
- ✓ **Cosmology:** When astronomical bodies are examined, only their exterior is studied. This is because; any light produced in the core reacts with gas particles and may take thousands of years to reach the crust. Since neutrinos are created in the core of stars as a product of interstellar fusion, the core can be analysed using neutrino astronomy. If a star explodes in the far side of the galaxy, interstellar dust would obscure our view. But the neutrinos would come through unhindered, with modern detectors giving us an unprecedented peek at the action. Back in 1987, neutrinos were the first harbingers of the dramatic demise of a massive, bloated star in the Milky Way. Scientists have observed that some neutrinos come from space and are produced from things like super massive black holes and particularly violent star deaths that produce gamma ray bursts. But they also think these high-energy neutrinos could be coming from decaying dark matter in nearby galaxies or from the cores of the Sun or Earth.
- ✓ **Detection of Mineral and Oil Deposits:**_Some scientists have proposed that intense beams of neutrinos could be used to probe the Earth's crust like how dentists use X-rays to scan teeth for cavities. Neutrinos change the way they spin depending on how far they have travelled and how much matter they have

passed through. So geophysicists have proposed that analyzing the way a beam of neutrinos are spinning after passing through pockets of the Earth could reveal where mineral deposits are.

- ✓ **Communication with Aliens:** Since neutrinos travel freely through space, proponents argue that they would make terrific messengers between advanced civilizations across the galaxy. This one is a little far-fetched, but since it is possible to encode messages in neutrinos, theoretically those encoded neutrinos could be beamed into space. Currently, scientists don't have the ability to beam neutrinos that far, and any aliens on the receiving end would have to be able to decode the message.
- ✓ **Medicine:** Scientists at the India-based Neutrino Observatory Centre, Madurai have proposed that it is possible to determine the size of tumours using neutrinos. A further advanced research suggests that neutrinos can also be used to treat cancer which doesn't cause any side effects unlike the gamma-radiation therapy.
- ✓ **Chemistry's Role in the Detection of Neutrinos:** Neutrino-hunting physicists plan to use chemistry to make more complex fluids with increased sensitivity to detect neutrinos. A neutrino interacts with the protons and neutrons of an organic liquid, and the reaction produces a flash of light. A fluorescent additive shifts the wavelength of emitted light to a detectable region. At China's Daya Bay project, the liquid is linear alkyl benzenes doped with gadolinium. This gadolinium adds another layer of sophistication to neutrino detection. When a neutrino's antimatter counterpart, an antineutrino, collides with a proton, the interaction produces a positron and a neutron. The positron produces one light flash. Gadolinium can absorb the neutron and emit gamma radiation, yielding a second flash that further confirms the antineutrino detection. The big challenge with combination liquids is making the water and the organic components—linear alkyl benzenes are still a favourite—miscible and stable for at least a decade, says Minfang Yeh, who leads the neutrino and nuclear chemistry group at Brookhaven National Laboratory. To help hold the solution together, his group has experimented with various surfactants, including polyethylene glycol octylphenol ether, commonly known as Triton X-100.

Conclusion:

Neutrinos build up the entire universe. Yet their existence and implementation are minuscule. They hold the key to a more evolved future. While the unavailability of efficient equipments seems to be the only barrier, scientists here at Theni, Tamil Nadu, have already made ground breaking studies on them. It is time to extend this knowledge.

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