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THE PHYSICS OF CONSCIOUSNESS

The leg was suspended by a rod made of a different metal, while the skin tissue connected both metals allowing a current to flow through the leg. This is similar to how a battery works (with two metals of different reactivity transferring ions). At the time, however, Galvani believed this was due to ‘animal electricity’ - a type of electricity that made up the life substance of the animal.

Mary Shelley, author of the first science fiction novel ‘Frankenstein’, allegedly used Galvani’s experiment HE as inspiration for the reanimation of inanimate parts. While we now know that animal electricity does not exist, the concept raises important questions about the nature of life. What makes the electricity that flows in our brains different from that in electrical circuits? Why can’t the brain be stimulated after death? And most importantly, what does it mean to be conscious, and are some forms of consciousness more conscious than others?

Consciousness is believed to be an emergent property, which means that we can’t understand consciousness by examining each individual neurone in the brain. Consciousness is the result of complex interactions within the brain, just like how we can’t explain the wetness of water by describing the wetness of a hydrogen atom and an oxygen atom because the atoms themselves are not wet (they only combine to make wetness).

Reductionism contrasts to emergence, because it suggests that all complex processes can be explained by breaking them down into smaller parts. When you experience something like pain, it is difficult to describe in words. Any feeling or sensory process is emergent because we cannot understand the flavour of an orange or emotional pain simply by looking at the electrical processes of the brain.

Electricity in the brain works very differently from electricity in electrical circuits. When we revisit something, the neural pathways strengthen to enforce a memory, which forms part of our experiences and what makes us who we are (known as neuroplasticity). However, electricity in circuits does not show this ability to adapt or organise itself to form a neural network. To create a conscious machine, it would require more than just electricity. Alan Turing argued that if a machine can convince a person that it is human, the thoughts of the machine are indistinguishable from the thoughts of a person, and the machine can therefore be thought of as intelligent. However, the issue with consciousness is that it is impossible to know for certain whether something is aware that it exists.

There are many theories that try to explain consciousness. In quantum mechanics (the study of small things), particles can exist in different positions or states at the same time, which is called coherence. Erwin Schrödinger proposed a thought experiment where a cat locked in a box has a 50% chance of dying and a 50% chance of living. Before the box is opened, the cat can be thought of as both alive and dead, so it is in multiple states at once.

This is the basis for quantum computers, which use qubits that can exist as both 1s and 0s simultaneously (allowing for faster processing). Quantum computers require extremely cold temperatures close to absolute zero so that qubits can maintain their coherence. Penrose and Hameroff proposed that a conscious thought occurs when a particle that is coherent ‘collapses’ into just one position/state. However, when a particle interacts with the environment it can lose coherence quickly. This is particularly problematic in the warm environment of the brain, so the theory doesn’t support sustained consciousness. Hameroff therefore proposed the idea of microtubules, which are small protein structures within neurones that allow for decoherence to produce conscious thoughts.

In quantum mechanics, particles exist in multiple states at once, but observing the particle causes it to collapse into just one state. For example, when we describe the position of an electron in an atom, we typically refer to its probable location within a cloud of possible positions. It is the act of looking at the electron that causes its location to ‘collapse’ into a single point (which is called wave function collapse).

Some theorists therefore believe that consciousness may play a role in causing the collapse of a quantum particle. Others believe that before we observe the electron, all possible states exist at the same time.

Some even take this idea further and suggest that all other states exist in alternate realities or universes. However, in microtubules, Penrose believes that it is gravity - not consciousness - that causes this collapse. This collapse is what then creates conscious experience. Gravitational fields are not stable when they are in multiple states at once, so the collapse causes a particle to go back in time, making it as if the other states never existed. Microtubules then organise each tiny collapse (called Proto consciousness) into a conscious thought.

This theory is called the Orchestrated Objective Reduction (Orch-OR) theory of the mind.

How can a particle appear to go back in time? Quantum mechanics allows for weird things. For instance, when two quantum particles are in contact with one another, they become entangled. This means that what happens to one particle instantly affects the other, even if the particles are separated by large distances. If a particle in New York collapses into a certain state, an entangled particle in the UK would instantly collapse into a predictable state. We don’t encounter this sort of behaviour in the normal world, so Penrose sought to explain the laws of the quantum mechanical world and how they differ to the classical world that we see. Essentially, when something collapses instantly, it only seems this way because the particle already collapses into a single state before we see it (because the particle goes back in time). Consciousness may therefore force us to follow linear time which does not apply to quantum mechanics. If that wasn’t mind-boggling enough, Penrose takes it a step further by suggesting that before we make a decision, all possible decisions exist in quantum superposition. When the state collapses to a single choice, all other choices never existed at all. This could be why, when we make unconscious decisions, we make them so quickly (because quantum mechanically, they have already been made.)

Penrose, building on the theory, suggests that consciousness is not computational, which means it cannot be thought of as a series of calculations or processes in the brain. This is partially inspired by Godel’s incompleteness theorem, which states that, within any mathematical system, there are mathematical statements that cannot be proved but nevertheless must be true assuming the maths is consistent, so there are no contradicting statements). If we can’t prove something, how do we know it’s true? Penrose thought that there must be a non-computational aspect of our brains that allows us to understand truths. If this is true, it would be impossible to give consciousness to a machine or inanimate object.

Penrose and Hameroff's theory is extremely controversial and remains speculative. If proven, it could radically change our ideas about consciousness and the nature of thinking. It would also have extraordinary implications for quantum mechanics and the classical world, since it may suggest that the laws of the microscopic world are incompatible with the macroscopic world. However, currently, there is little scientific evidence to support the theory. The science of consciousness remains elusive and complicated, with theories that are difficult to test and confirm. For now, the question remains open – but who knows what the future holds?

BY MISHKA K 12B

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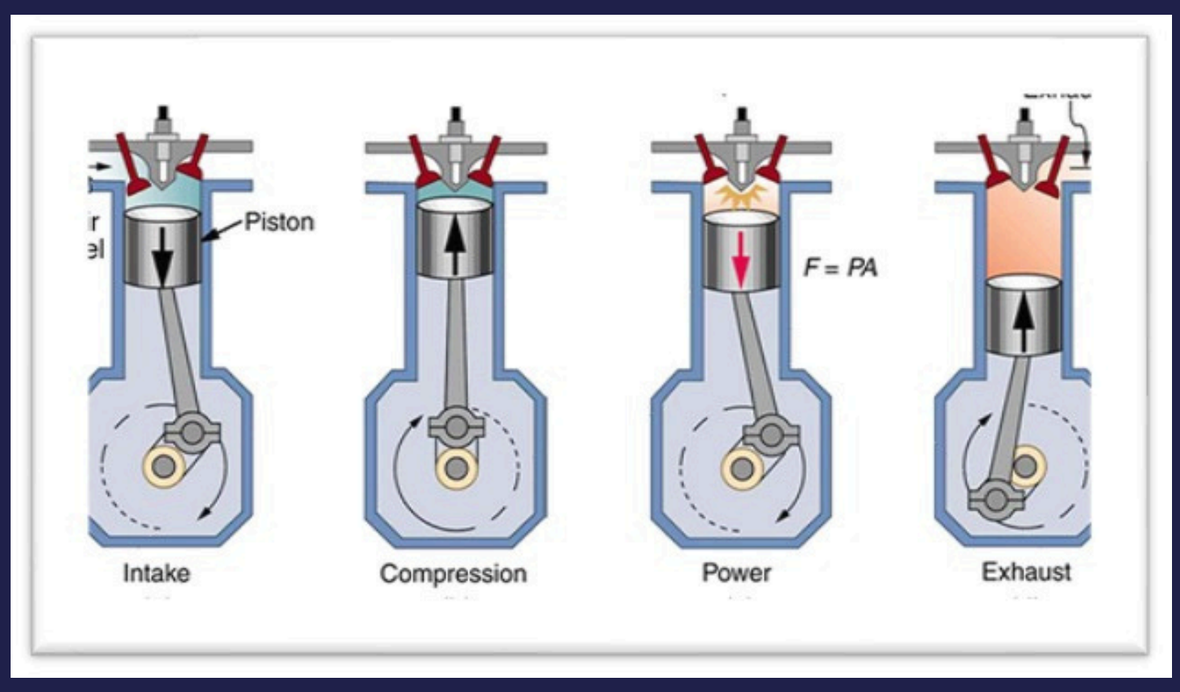
HOW A MAN DROVE ACROSS THE USA IN HALF THE VOLUME OF FUEL HE NEEDED

Earlier this year, September 2024, Gerard Gerdes broke the Guiness World Record for lowest fuel consumption when travelling from the East Coast to the West Coast of the United States with an average use of 2.5 L/km of fuel when the Toyota Prius LE he drove advertised a rating of 4.1L/km. To understand how Gerdes (who coined the term ‘Hypermiling’ to describe this feat) was able to do this, we need to understand how a car engine works and how fuels are translated into the kinetic energy that propels the car forward.



The Prius is a hybrid vehicle, using both an Internal Combustion Engine (ICE) and an Electric motor. Now, the efficiency of an electric motor is easy to take advantage of. The motor uses a stator to induce a magnetic field, with a rotor carrying an electrical current in its presence, which generates force and causes it to spin. By using battery power, and not a fuel, around 65-69% of the energy generated goes straight to the wheels and very few parts are needed to allow this to happen. Unfortunately, the same cannot be said for the ICE. These are powered by the combustion of fuels that moves a piston attached to a crankshaft that causes the wheels to turn. The exact way this piston works is that as the piston lowers, the surrounding cylinder is sprayed with air and fuel, causing it to rise again and the air-fuel mixture compresses. A spark is then introduced causing a combustion reaction to occur and the increase in temperature and pressure lowers the piston once again and the cycle repeats. However, in this process a lot of energy is wasted and only around 16-25% goes to turning the wheels as well as the negative environmental

impact, with ICEs making up around 15% of total global emissions but the combination of ICE and electricity use allow for the vehicle to be efficient, affordable and practical, as finding fuel for petrol and diesel engines is far easier that electric chargers.

One of the main techniques used by Hypermilers is the ‘pulse-and-glide'. This works by the driver accelerating slowly until they are a little above their desired speed, then slowly decelerating until they are below the speed and then repeating this process instead of travelling at a constant speed. The reason this works is because car engines work at higher efficiencies when accelerating in comparison to working at lower consistent speeds. Additionally, most modern cars also turn off fuel injection when decelerating, meaning their wheels are powered by inertial forces and not fuel combustion, thus saving fuel.

Hypermilers are constantly trying to break records and find the most efficient uses of their vehicles, considering engine use, weight of the car, their routes and the landscape and will likely continue to find new ways of manipulating the mechanics of car engines to do so.

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THE RECTANGULAR SUN

In January 1597, William Barentsz, along with his crew, embarked on his third polar expedition to the Arctic in search of a Northeast Passage connecting the Atlantic and Pacific Oceans. Unfortunately, Barentsz's ship became trapped in ice, forcing the crew to spend the winter on Novaya Zemlya, a remote archipelago in the Arctic Ocean off the Russian coast, where they were isolated during the polar night. During this time, Gerrit de Veer, one of Barentsz's crew members, witnessed an extraordinary event: the Sun appeared above the horizon two weeks before its calculated return. When de Veer recounted his observation to the crew, he was accused of misreading the calendar and his claims were dismissed. However, three days later, the Sun reappeared, and this time, Barentsz and the rest of the crew saw it as well. Upon returning to the Netherlands, de Veer published an account of the expedition and his observations, documenting what would later become known as the Novaya Zemlya effect.

The Novaya Zemlya effect is a rare optical phenomenon and mirage caused by the extreme refraction of sunlight through layers of air with different temperatures. Under specific conditions found in polar regions, the Sun appears to rise earlier or set later than it should, even when it is physically below the horizon. Sometimes, the effect alters the Sun's shape, transforming it into a flattened line or a square, often known as the "rectangular sun." This phenomenon can also lift the images of other objects like distant coastlines above the horizon, making them visible from afar.

The Novaya Zemlya effect is caused by a strong temperature inversion, which is when a layer of cold air is trapped beneath a layer of warm air. These inversions are common in polar climates, especially above ice surfaces. When sunlight enters the cold layer and passes into the warmer air, it is refracted back toward the denser, colder air.

If the refraction is strong enough, the rays bounce up and down inside the duct, creating multiple oscillating paths, and rays of light are channeled along the curvature of the Earth by total internal reflection for several hundreds of kilometers. This effect creates the illusion that the Sun is above the horizon, even though it is below it. This leads to stacked lines being formed, with black bands between them. Each slot represents a compressed, full-width image of the Sun, resulting in the "rectangular" appearance of the sun due to the Novaya Zemlya effect.

However, this effect is not limited to just the polar regions and can sometimes be seen from the coast of California. Strong temperature inversions can occur due to warm air rising from the land and cold offshore sea currents. This creates conditions where weak refraction of light can occur, producing a less pronounced Novaya Zemlya effect. This creates a “mock mirage” of three or more segments of the sun.

This phenomenon provides scientists with valuable insights into the behavior of light in the Earth's atmosphere and has practical applications. Understanding extreme refraction helps improve the accuracy of astronomical observations, navigational systems, and climate models, especially in polar regions. This fascinating phenomenon demonstrates the power of atmospheric optics and nature’s captivating beauty. It continues to intrigue scientists and is just one example of numerous natural phenomena that defy our expectations and fascinate us.

BY ISHA P 12P

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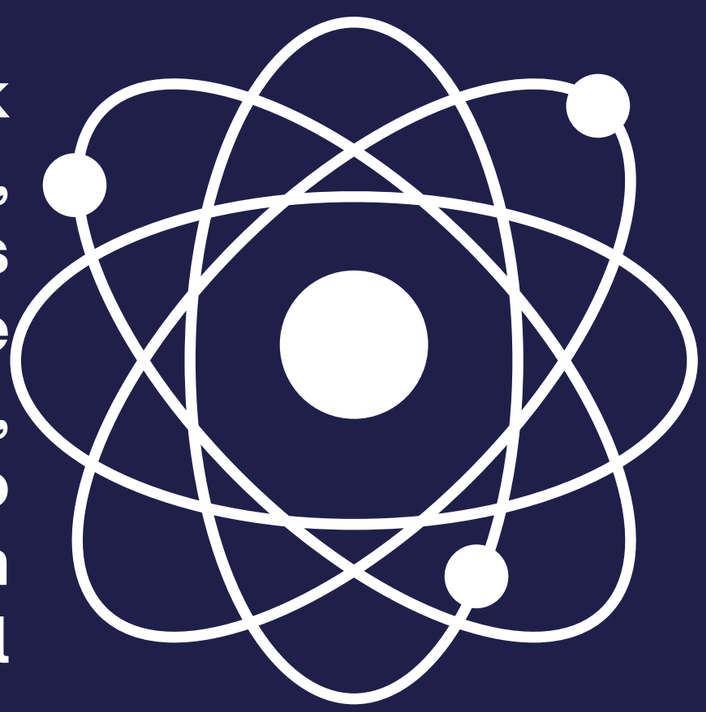
THE HIERARCHY PROBLEM

It’s rather uncommon in life, to have three sets of data that are relatively similar to each other, and then one data set that is so far removed in its values that it almost seems like a product of tremendous errors, or a cosmic joke. This, however, is a problem that plagues physicists to this day.



The Universe consists of 4 main forces, the weak force (interactions between subatomic particles), gravity (the force of attraction between objects having a certain mass), electromagnetism (the force between charged objects via electric fields), and the strong force, the force binding quarks into protons and neutrons). The Hierarchy problem stems from two constants, the Gravitational constant from Newton’s Gravitational theory, that

being: F = G (m1m2/r^2) where G= 6.67 × 10^-11, and Fermi’s constant, also called the Planck Mass, stemming from Fermi’s desire to form a constant derived of universal constants. It is stated as such: GF/(ħc)^3 , this is as a combination of Newton’s gravitational constant G, Planck’s quantum constant h-bar, and the speed of light c: the Planck mass is the square root of h-bar times c divided by G. Its value is 2.17645×10−8 kg. A surprisingly large value compared to the value of G. The W and Z particles, particles responsible for carrying the weak force, have masses up to 1016 times smaller than the Planck Mass. This is the ‘hierarchy’ between the forces of gravity and the weak force.

In the 1970’s, physicists realized that the size of the non-zero Higgs field determined the size of these W and Z particles. The non-zero Higgs field has a size of about 250 GeV, and that gives us the W and Z particles with masses of about 100 GeV. However, quantum mechanics tells us that the Higgs Field has an unstable size, and there seems to be only two natural states for the Higgs Field, zero, or the Plank Energy (the energy equivalent of the Planck Mass), a value that is 1016 times greater than what it’s observed to be. Most inconsistencies that occur in physics can sometimes be explained away by ‘corrections. No ‘quantum correction’

has yet been able to explain the hierarchy problem.

Supersymmetry is one theory that seeks to solve the Hierarchy Problem, and can protect the Higgs mass from quantum corrections. String theory, once thought of to be ‘The Theory to Everything’ is a framework in which particles are replaced by one dimensional ‘string’. The interactions of these ‘strings’ make up the framework of the universe. String theory states that every particle that interacts with the Higgs Field has a ‘Yukawa Coupling’ λf.
When coupling with particles like the electron, neutrons and protons, the Higgs Field will naturally gravitate to the heaviest particle, most often a top quark. The same is done for another set of particles called bosons. The quantum correction observed from the interactions of both these particles seem to set the Higgs Field mass down to 0.

The theories of supersymmetry are being tested at the LHC, though no evidence has been found yet. Another theory suggests the need for further dimensions in order to understand the difference in the forces, as it suggests that gravity is weak as it loses its powers to the other dimensions. Others have argued that there is nothing to explain, because of a selection effect: the universe is far larger and far more diverse than the part that we can see, and we live in an apparently unnatural part of the universe mainly because the rest of it is uninhabitable — much the way that although rocky planets are rare in the universe, we live on one because it’s the only place we could have evolved and survived.

Many of these solutions hope to be solved at the Large Hadron Collider, but whether a solution will be found soon remains to be seen.

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THANK YOU FOR READING!