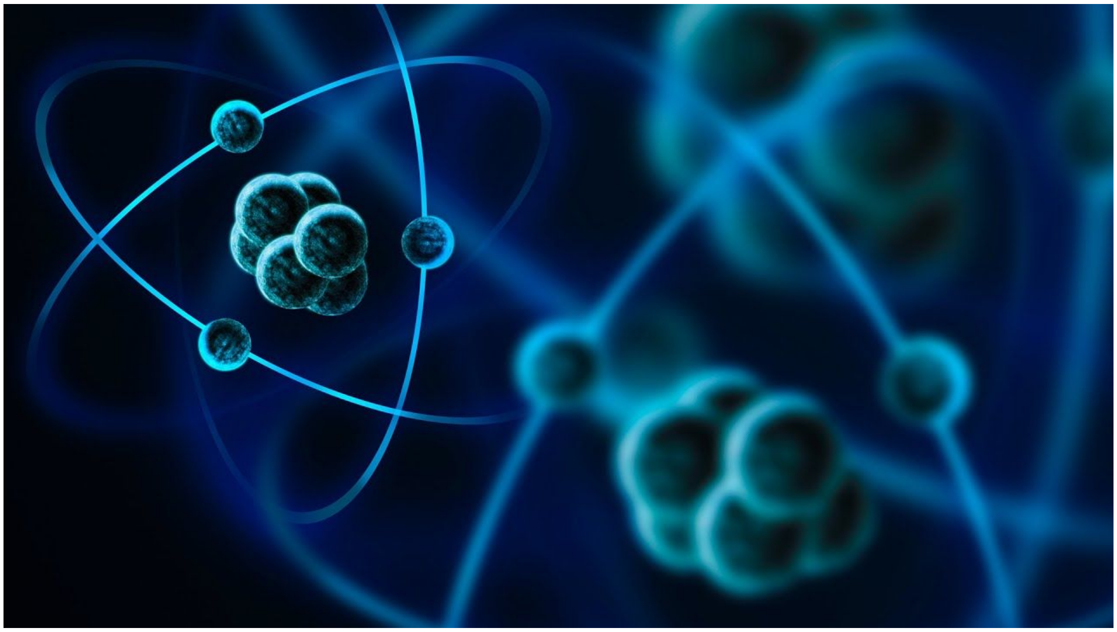
# Physics Newsletter

February 2021



Disclaimer: we are not responsible for any existential crises or melting brains

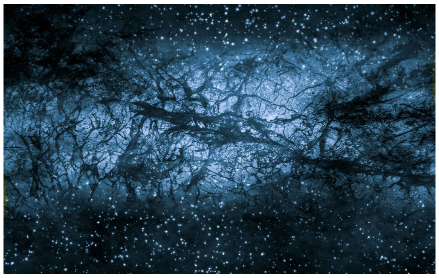
Hi guys,

Welcome to the February edition of the physics newsletter. Thanks to our contributor, Sreyaa from 9W, we have an even longer newsletter to quench your thirst for physics. We hope you'll enjoy it. :)

In this edition we will discuss:

- Dark Matter and Energy - Sreyaa Sunjay 9W
- Quantum Entanglement - Vanshika Gupta (15guptav699@kechg.org.uk)
- Magnetic Graphene - Siyma Chowdhury (15chowdhury914@kechg.org.uk)
- The End of the Universe - Maheen Abir (15abir780@kechg.org.uk)

# Dark Energy and Dark Matter



The sun, galaxies, other stars only take up 5% of the mass of the universe. Only 5%!!! So the rest of the universe is made up of dark energy and matter, an invisible force. We know it exists because visible matter doesn't have enough gravitational power to hold everything together. But we still don't know exactly what dark matter and dark energy, nor what their properties are.

**So what is dark energy and dark matter?**

Dark energy (70% of the universe) is an unknown force that repels gravity. Dark matter (25% is an unknown force that attracts gravity. This is the force that is expanding our universe. Not a lot is known about it because it is invisible to light and forms of electromagnetic radiation so scientists haven't been able to observe it directly. Dark matter can't be seen but its impact can be felt, it draws matter together.

**The universe expanding?**

By the 1990s one thing was for certain; that gravity was definitely going to slow down the expansion of the universe. No one had recorded this, but it was bound to happen. The reason for this is that the universe is full of matter and gravity will pull it all together. But then 1998 came along and observations made by the Hubble Space Telescope showed that distant supernovae were expanding, so the idea that gravity was slowing down the expansion of the universe was wrong because it was accelerating. No one knew what this was about and no one expected this. Theorists came up with a few ideas but we still don't know what it is exactly but they came up with a name for it; dark energy.

**Optical illusions?**

Dark matter might explain some interesting things we see in the deep universe. When we take pictures of galaxies we sometimes see these weird rings or arcs and an explanation for this could be that light, from further galaxies, is being distorted and magnified through dark matter - it is called gravitational lensing.

**Why is studying dark energy important?**

It is really important to try and understand this mystery because it is literally the future of the universe. Trying to figure out what this is about will help us try to grasp what the size and shape of the universe will be like, whether it will continue to expand or stop and collapse, whether it will stop when it reaches equilibrium. Understanding this complex force will also help us decipher how galaxies and clusters form and evolve. For example, when a galaxy starts spinning theoretically it should break apart. But this doesn't happen because gravity keeps it together; but the amount needed (which is a lot) could not be generated by visible matter. To fully understand the cosmos, we need to understand dark matter.

**What next?**

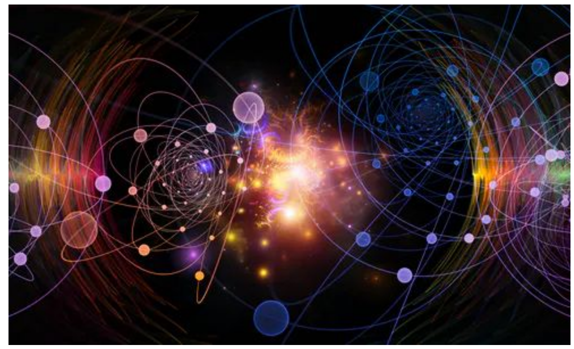
Continuing to research this fascinating field is crucial because it will help us unlock the gridlock around the universe. Dark matter is a force we haven't even seen yet, making it even more mysterious. We don't really know how it came about or what it could possibly do which makes it even more interesting. We already have a few ideas about dark matter but no one (yet) has an explanation about dark energy which makes researching and studying all the more necessary.

By Sreyaa Sunjay 9W

# Quantum Entanglement

The quantum realm is entirely another universe with by far the weirdest concepts in all of science. So be wary as I introduce you to the many bizarre concepts in physics.

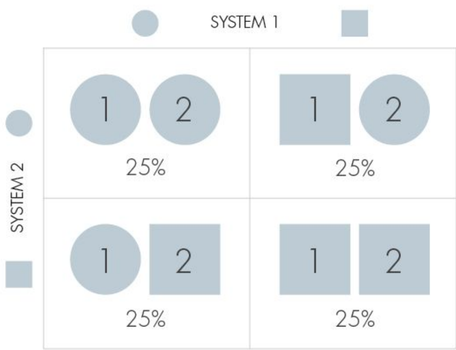
I'll start with a summary of what this is. The phenomenon says that if two particles, or sometimes even more (but let's not think about that) interact with each other, they become entangled. This means that their states (properties of a particle) correspond to each other. So in a pair of particles, the states of both particles are almost dependent on each other. If the state of one particle in the pair changes, the other particles' state also changes *instantaneously*. This can happen no matter how far apart they are, and they are not physically connected either.



There's a pretty common analogy to describe this concept. There are two people: let's say Bob and Alice. They each take a glove from a pair and put it in their boxes, and they don't know whether they have selected the left or right-hand glove yet. They go some distance apart and Alice opens her box. She finds out that she has the right-hand glove and instantly knows that Bob, therefore, has the left glove. That's effectively quantum entanglement simplified, the knowledge of the state of one particle tells you about the state of the other.

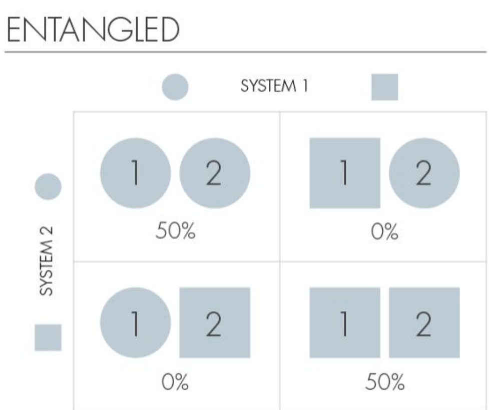
In a mathematical sense, this theory is all just probability allowing us to predict the properties of entangled, linked particles. This is because there are certain rules to the states. For example, let's say there are 2 states both the particles can be in- one being *circles* and the other *squares* (it's random), with states being some kind of property like spin (the angular momentum and orientation of a particle in space as you'll find in Siyma's article if you read on). You can just think of it as something that tells us more about the particle. No, they do not communicate as per se, nor does finding the state of one particle "change" affect the other particle. It is just that after the measurement of one particle, the outcome of the second particle is more *predictable*.

**Independent States**




I know most of you have done some sort of probability by now so understanding the chart on the left should be okay. We are still thinking, and will always think about two particles e.g electrons or photons (packets/group of light energy).
When the particles are independent, their states do not affect each other as you would think. So the combinations of states would be like this and the probability of them coming in that combination is written in the table.

**Entangled States**




If you decided to test quantum entanglement, you would find that if you simultaneously measured both particles, no matter how far apart they were, the results would be correlated. There would be a distinct pattern. For example, here is a rule I mentioned there would be earlier: if the state of the first object is a circle, then the state of the second object must also be a circle. If the state of the first object is otherwise square, the state of the second object would also be square. So clearly there would be a correlation between the states and we call this entanglement. The probabilities of the combined states therefore when these rules of entanglement apply, are next to this paragraph.

Another tiny detail I must add to the description of quantum entanglement is that there's a thing called superposition, where an object can be simultaneously in many states. This applies to particles as well, they are in superposition until measured and are forced into becoming one state. Like a spinning coin is both heads and tails till it stops spinning and lands on either side. When they are measured, that is when entanglement takes place to be useful.

This is not to say that the particles communicate, they do not have a consciousness. One interpretation that you will see many times if you are researching this topic is that the particles communicate with each other. They exchange information between them at speeds higher than the speed of light in order to tell the second particle to "change" into the other correlated state because even if the two particles are galaxies apart and you measure one of them, you would instantly know the state of the other. This shows that if they did communicate, they would do so faster than the speed of light as the states influence each other. However, nothing can go faster than the speed of light because this would break general relativity. This is the problem I mentioned earlier by thinking that the particle changes on command- it would be better to think of both the particles as one. Like a seesaw, if one side goes up the other must come down.

Einstein's idea of how this concept works is based on hidden variables, something that is predetermined by the particles but we do not know about. You can think of it as if they have a plan before they are measured to become a certain state. Now this idea does not involve faster than light communication- however there are still debates in the physics world as to if this idea works.

There are many uses, but research is still being done to find more practical applications of this complex theory. Some of the uses include:

- Quantum Computing ( as mentioned in a previous article)
- Quantum Cryptography
- Theory of quantum teleportation
- Improved Microscopes

So on a basic level, that is quantum entanglement, a means by which we can predict the properties of intertwined particles. There are still many things that don't make sense. In fact, a famous physicist has said that if you think you understand quantum mechanics, you don't. But specifically to this topic, I think a Chinese proverb matches quite well, "An invisible red thread connects those who are destined to meet, regardless of time, place, or circumstance. The thread may stretch and tangle, but it will never break."

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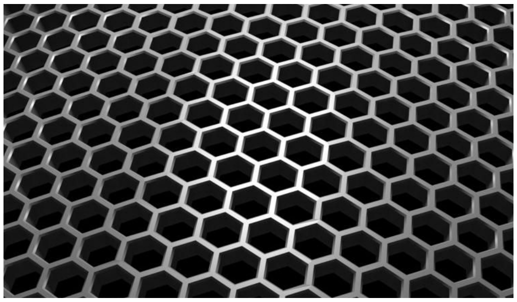
-Vanshika Gupta

## Magnetic Graphene

Judging from the title, you probably hope this won't be too mentally challenging. It's not called something random with "quantum" stuck at the beginning, so what could go wrong? Let's just start with the basics before we get ahead of ourselves:

**What is graphene?**



Graphene is a 2-dimensional layer of graphite, which means it has a thickness of only one atom. Its existence was theorised and speculated before it was first made in 2004 by researchers at the University of Manchester. Without going into too much detail about how it was made, let's just say some sticky tape was involved…
But the compound it is derived from is also interesting, which is why the properties of graphene intrigued scientists before it was even synthesised. As most of you will know from year 9 chemistry, graphite is an allotrope of carbon. Each carbon atom is covalently bonded to 3 other carbon atoms, leaving one delocalised electron per atom to allow a current to flow through the material. This special property of electrical conductivity has made graphite suitable for several electronic applications such as batteries and electrodes.

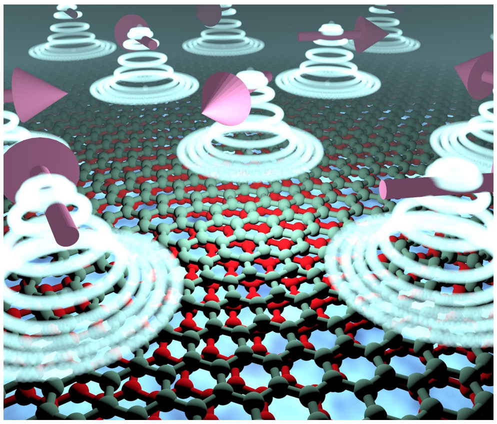
**What is magnetism?**

Over the past few years, you'll have learnt that magnetism is a non-contact force which is experienced by certain metals. There are two poles called north and south, and similarly to charge, like poles repel each other, while opposite poles attract each other. Magnetic metals are also known as ferrous metals. Some ferrous metals can be made permanently magnetic while some are only magnetic when induced by another magnet nearby.

**But what causes magnetism?**

In part, magnetism can be said to be caused by the motion of electrical charges. So if something as small as an electron is moving around then it can develop a magnetic field. But if an electron isn't moving it still is affected by magnetic fields and forces. To explain this physicists created the idea of spin. Spin is a quantum property and according to Wikipedia is "an intrinsic form of angular momentum carried by elementary particles", the intrinsic part means that the property is within the object itself and angular momentum is just like normal, linear momentum but rotational. There are several problems with the idea of spin, one of them being that it's very hard to make sense of and it doesn't actually refer to electrons spinning. It's more useful as an analogy but even then, calling this quantum property "spin" carries with it various ways to misconstrue what it is. By doing some very complicated maths, it can be calculated that just for the idea to work an electron would either have to be bigger than the atom, while rotating on its axis or rotate at about one million times faster than the speed of light. So essentially the idea that an electron is just a tiny ball of stuff spinning is...wrong. But let's just define spin as the reason why magnetism happens and unfortunately, if you're unsatisfied with that, just think about charge, it's not something that we see as peculiar but there is no solid definition.

The link between spin and magnetism is that in non-magnetic substances, the spin of electrons in atoms cancels out, there is an equal number of electrons with opposite directions of spin. But in ferrous metals such as iron and nickel, most of the electrons have the same direction of spin, making it strongly magnetic. They aren't quite magnets but they can become magnetised, by entering the magnetic field of an existing magnet. Permanent magnets have all of their spins aligned in the same direction, a behaviour which is referred to as ferromagnetism.



Using all the aforementioned information, scientists at Aalto University have been trying to manipulate spin and a new quantum property called the "valley" to enhance information processing. In the quantum world, spin can be arranged in several exotic ways which can lead to both amazing properties and entangled magnets. This new property, similar to spin, is seen in graphene and may give way to a new field of research, "valleytronics". Slightly twisted layers of graphene have displayed such unconventional properties potentially leading to an entirely new group of materials that can be used for quantum technology.

^ "Schematic of a valley-spiral in magnetically encapsulated twisted bilayer graphene."

But how did they do this? They sandwiched two slightly twisted layers of graphene in between a magnetic insulator and found that it provided a unique environment for electronic states. All of these factors decided the electron's behaviour and showed how valley states can be generated.

So there we have it, magnetic graphene. Besides graphene being an awesome semiconductor it has really cool magnetic properties and hopefully if this article made any sense, you'll know why. This discovery has so much potential, possibly leading to more advances in what materials we could use for things such as quantum computing and information processing in the future.

Here are some of the links I used, you can also find a lot about spin with the videos :)) - Siyma


- https://www.nationalgeographic.org/encyclopedia/magnetism/#:~:text=Magnetism%20is%20caused%20by%20the%20motion%20of%20electric%20charges.&text=Each%20atom%20has%20electrons%2C%20particles,act%20like%20a%20microscopic%20magnet.
- https://www.youtube.com/watch?v=cd2Ua9dKEl8
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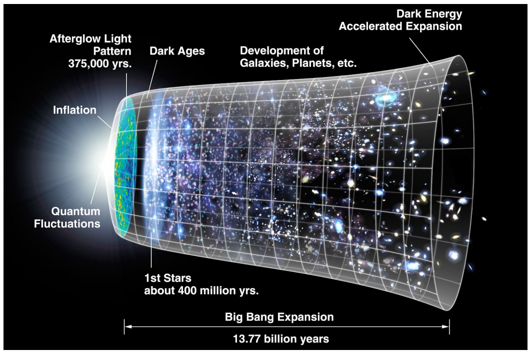
# The End of the Universe

The most accepted theory on the universe's beginning is the Big Bang (whose name was, ironically, coined from a sceptic, the astronomer Fred Hoyle). It states that the universe originated from a tiny, singular point of extremely high temperature and density and has since continued to expand until the present day, in which we find ourselves surrounded by billions of planets, stars and galaxies just like our own. But all things must come to an end, even our universe as we know it. Just how will this happen? In this article I'll be discussing the most widely accepted theory: the heat death, or the 'Big Freeze'.

Considering our universe is 14 billion years old, it seems strange to call it young. However, due to the vastness of the timescales with which we are dealing, 14 billion years is like a second when compared to the trillions upon trillions of years the universe will continue to expand at an accelerating rate due to the influence of a mysterious force called dark energy. Dark energy is estimated to comprise 69% of the universe's total mass, which is impressive for something that can't even be directly detected. As the universe continues to expand, it will move through five stages (first proposed in 1999 by Fred Adams and George Laughlin in their book, *The Five Ages of the Universe: Inside the Physics of Eternity*, and since supported by many astronomers).

**Primordial Era**

This era was from the Big Bang to the creation of the stars. For the first $10^{-44}$ seconds of the universe's life, the laws of physics did not exist, a phase known as the Planck Epoch. Straight after this, rapid inflation began. The universe began to cool down as it grew and Big Bang nucleosynthesis - the production of nuclei larger than the hydrogen isotope hydrogen-1 - took place, creating simple elements like helium, hydrogen and very small amounts of lithium. In some of the more energy dense areas, the force of gravity caused the first stars to begin to form.



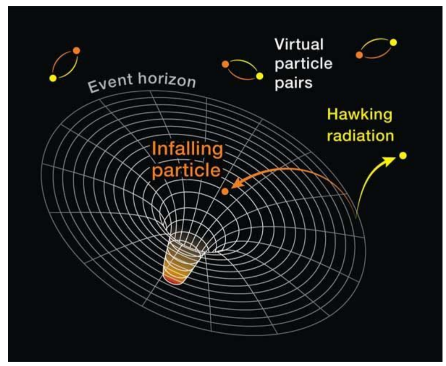

**Stelliferous Era**

This is the current era of the universe's growth. Most of the matter and energy in the universe can be found within stars and galaxies. The first stars, thought to be hypergiants (incredibly massive stars that could dwarf even the supergiant stars), exploded in violent hypernovae and contributed to the formation of smaller stars which clumped together into galaxies. At present, the universe is very active, with new stars constantly forming and galaxial collisions occurring. For example, in 4 billion years the Milky Way will merge with its neighbouring Andromeda galaxy to form a structure dubbed the 'Milkomeda galaxy'.

**The Degenerate Era**

A quintillion years after the Big Bang begins the Degenerate Era, long after the death of our Sun (and Earth by extension) and every other star. Living up to its very exciting name, this is an era in which only the remnants of stars continue to exist. 'Degenerate stars', like brown dwarfs, white dwarfs and neutron stars dominate the cosmos during this time, making for a rather dimmer and much more uneventful universe. Since the universe at this point is so vast, gases are too spread out to form new stars. Heat in the universe begins to be distributed more evenly, and, as a result, the temperature asymptomatically moves towards absolute zero (the point at which particles stop vibrating, -273°C). There are occasional bursts of energy in the form of stellar collisions to form new stars, but these are short-lived and few. Black holes devour stellar remains and grow.

**The Black Hole Era**




After even the corpses of stars have vanished, black holes will be the dominant force in the universe, holding the position for a long time, and remaining as the only place where organised matter continues to exist. But even they will begin to evaporate through Hawking radiation. In this process, particles are created at the event horizon and, though most fall back into the black hole, some are emitted, so the black hole loses a little of its mass. This is a very slow process, however, occurring on a timescale of trillions upon trillions of years. After the last black hole has evaporated, only a few tiny subatomic particles and photons will continue to exist in the universe.

**The Dark Era**

The final stage of the universe's life and by far the longest is the Dark Era. In this period, nothing will exist. The universe will effectively be an empty vacuum with hardly any activity. Occasionally electrons and their antiparticle counterpart, positrons, will collide to form extremely unstable positronium atoms that last only a short period of time before the particles comprising them annihilate. Other than this and a few other negligible annihilations, the universe will become a cold and empty void, its violent, fiery beginning reduced to a faint memory. This is what is referred to as the heat death or the Big Freeze; energy in the universe is evenly distributed, which means it has reached thermodynamic equilibrium. The absence of temperature differences means that no work can be done.

It is important to note that this particular end is nowhere near in sight. The Stelliferous Era is still fairly young, and stars like our Sun will continue to shine for many more billions of years. Conditions are also still ideal for the formation of new stars. Additionally, this theory is only a model that predicts one possible future. There are several other theories that model a particular path that the universe will follow towards its end, like the ‘Big Rip’ and the ‘Big Crunch’. Predictions about the ultimate fate of the universe are constantly subject to reevaluation as more new facts come to light.

If you’re interested in finding out more, I’ve put my sources below as a good starting point. Hope you enjoyed reading and look forward to next month’s edition of the physics newsletter :) - Maheen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