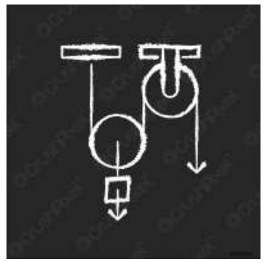


# PHYSICS NEWSLETTER

## May 2021

Please take a minute to fill out this physics survey :)
https://docs.google.com/forms/d/1cA6bj4S7AU56UwXildeRG9ipSZavV38wI1kNmUMJlFs/edit

Hey everyone!

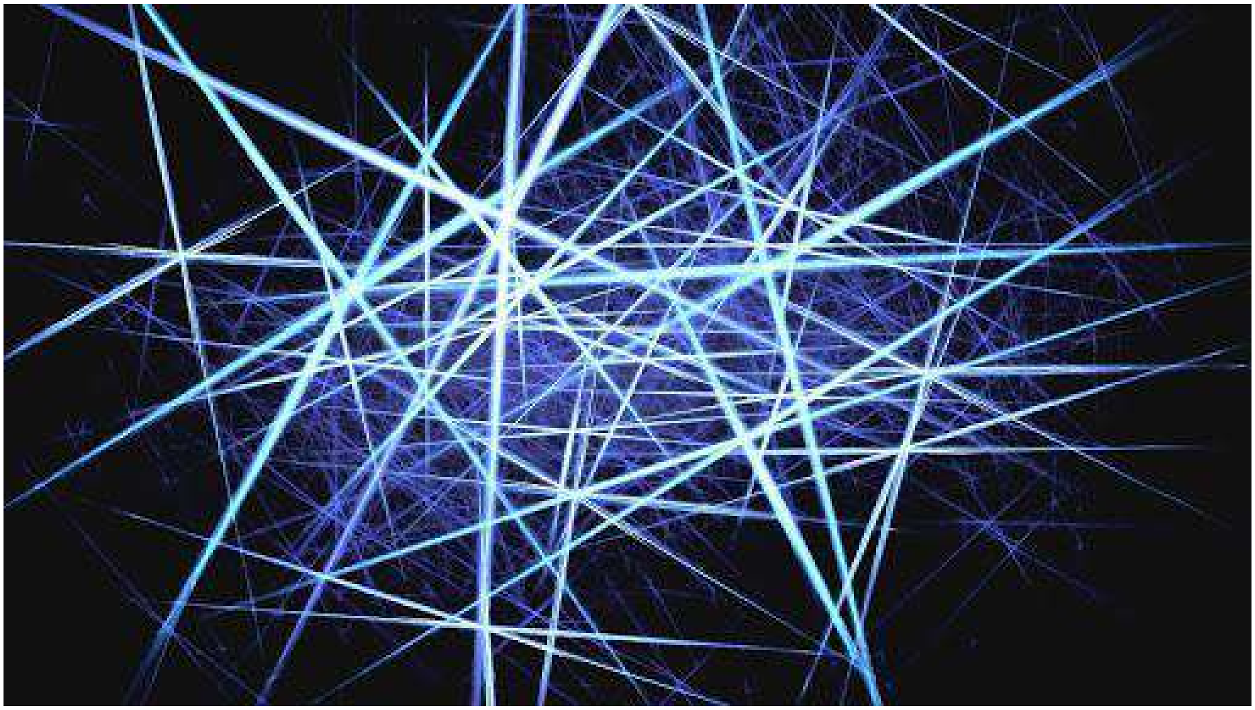
This month we are pleased to welcome a new editor, Vaidehi. We are also sorry to say goodbye to Siyma, who has been an editor since the start of this year. But fear not, because she'll still be writing articles for the chemistry and engineering newsletters! Be sure to check them out. Also, a huge thank you to Kavya for contributing a great article this month!

If you have any questions about our articles or would like to contribute to the next edition of the newsletter, feel free to email us :)

In this edition we will cover:

- Lasers - Vaidehi Kadhane (15kadhane570@kechg.org.uk)
- The Fifth State of Matter - Vanshika Gupta (15guptav699@kechg.org.uk)
- Time Dilation and Time Travel - Maheen Abir (15abir780@kechg.org.uk)
- Superconductivity - Kavya Sathish (15sathish725@kechg.org.uk)

# Lasers



First off, hi I'm Vaidehi, and I'm one of the new writers for the Physics Newsletter! I'm interested in studying Physics at university so my articles will consider a range of fascinating physics topics which you may not have studied at GCSE/A-LEVEL. I hope you find them as interesting as I do! :)

The Physics of Lasers

- What are Lasers
- How Lasers Work
- How wavelength affects Lasers
- NIF- National Ignition Facility
- Uses

*Laser: **L**ight **A**mplification by **s**timulated **E**mission of **R**adiation.*

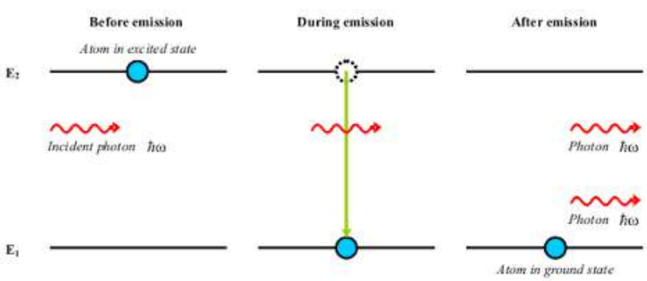
A laser is a device which emits a very intense beam of monochromatic (using only one colour) light which is coherent (has the same frequency, in phase, but not necessarily has the same wavelength?).

**How Lasers Work**

**The following paragraph may only be understandable to A-level Physics students...**

Lasers produce light by a process known as 'Stimulated Emission'. When an electron in an atom is in its excited state, if a photon has energy equal to the difference in energies between the electron in its excited shell and the shell below (which, by the way, will have a lower energy since it's closer to the nucleus), the incoming photon will stimulate the electron to drop down to that lower energy level and release a photon of the same energy. Therefore, the photons produced have a constant frequency(because they have the same energy) and phase difference, therefore creating coherent light. This process may remind you of the Photoelectric Effect.

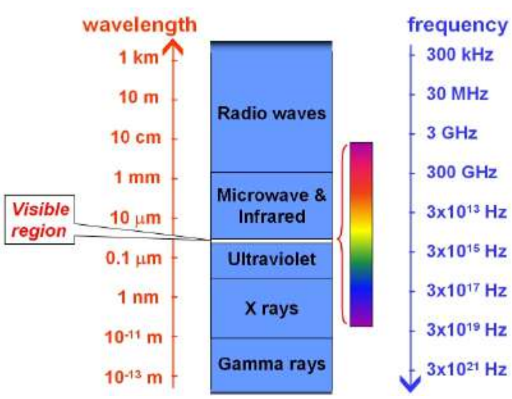
**How wavelength (the distance between successive crests of a wave) affects lasers**




As you may or may not already know, the wavelength and frequency of light affects its characteristic [c=f/λ]. For electromagnetic waves (reminder: these all have the same speed (3 x 10^8 m/s)), as you change the wavelength and frequency you will also be able to change the type of light produced.

Higher frequencies will produce more powerful lasers.

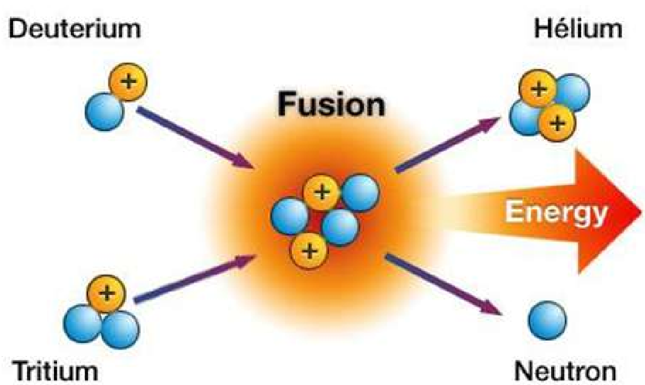
E=hf (the energy per photon)is also true, which means that as you increase the frequency the energy per photon also increases.




**<u>NIF- National Ignition Facility + The Uses of Lasers</u>**

Whilst researching for this article, I stumbled across the NIF, something I had never heard about but seemed interesting, so here I am talking about it.

The NIF is a large laser based INERTIAL CONFINEMENT FUSION (wikipedia could explain it better than me so: *"is a type of fusion energy research that attempts to initiate nuclear fusion reactions by heating and compressing a fuel target, typically in the form of a pellet that most often contains a mixture of deuterium and tritium.'* ) based research device located in California (near where I was born actually!). Lasers are used to heat a small amount of fuel to hopefully induce a nuclear fusion reaction. If you're in Year 11, you may already be aware about what this is, but here is a brief summary anyways. During nuclear fusion reactions, two or more nuclei are combined to form other subatomic particles, which can result in the release or absorption of energy.




NIF's aim is to achieve 'fusion ignition', which is the point where a reaction becomes self-sustaining: as much or more energy "out" than "in".

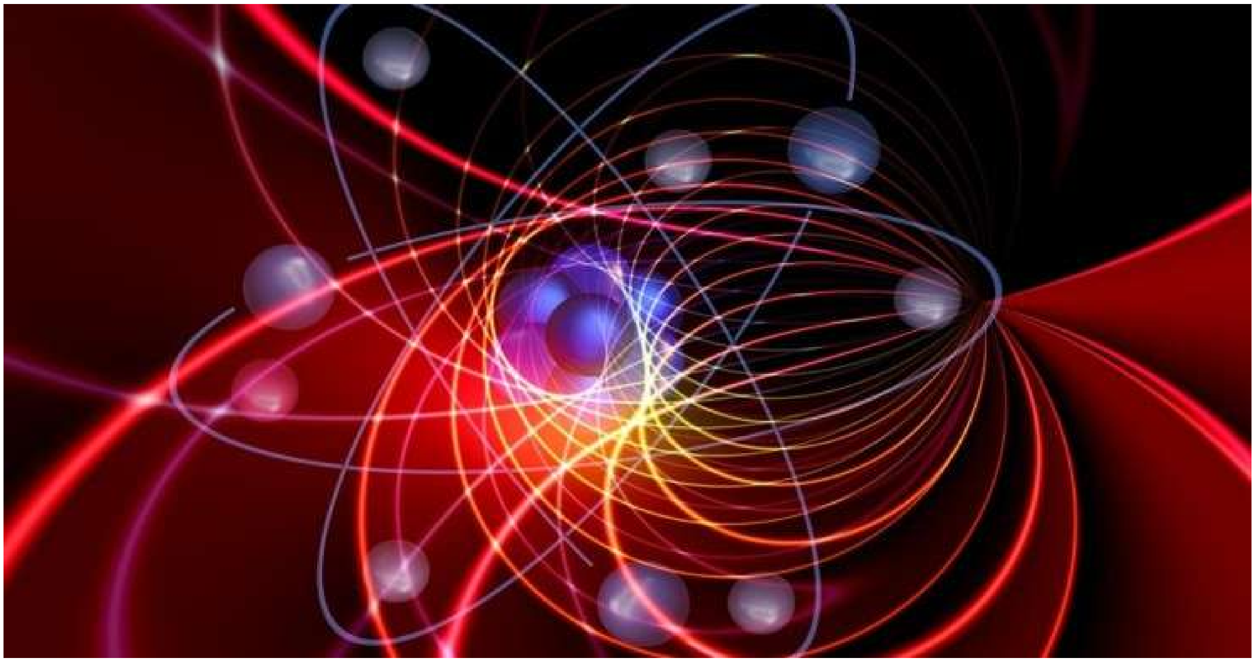
NIF has enabled scientists to create extreme states of matter, including temperatures of 100 million degrees!!

So there we go. Hopefully that was a short, understandable crash course about lasers and their uses. Let me know if you have any questions!

~ Vaidehi

- A lot of the information about NIF I stole from Wikipedia. Credit to Wikipedia, as unreliable as it sometimes may be: https://en.wikipedia.org/wiki/National_Ignition_Facility#:~:text=The%20National%20Ignition%20Facility%20.

# So There's A 5th State of Matter



Most of us know about the three states of matter: gases, solids and liquids. But there are always things that teachers don't tell you - for a reason, too. There are two more states of matter so we have objects that can be in the 1st, 2nd, 3rd and then 4th and even 5th state. The fourth state is plasma (which we won't talk about today but by definition is 'a gas into which sufficient energy is provided to free electrons from atoms or molecules and to allow both species, ions and electrons, to coexist'). Finally, we have the 5th state of matter, a Bose-Einstein Condensate (BEC), which sounds very cool.

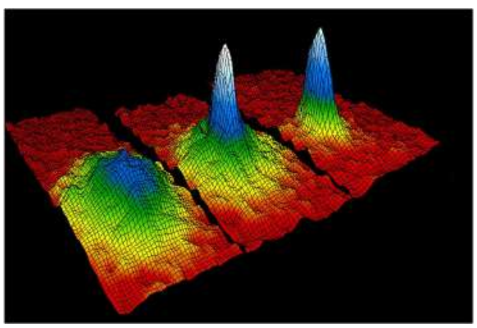
Einstein was involved in an amazing amount of theoretical physics which has shaped our modern day outlook, but this was not his contribution alone. It all started with Satyendra Nath Bose in 1942, who was working on quantum mechanical statistics when he sent his paper to Einstein. Einstein helped generalise his theory so his idea wasn't only applicable to light but atoms too- and that's where BECs come into play.

Random fact: bosons, which I will talk about in a bit, are named after Satyendra Bose.

So what are they? When you think of states of matter, you probably think about them in terms of particles, but what if these particles became waves? What would happen? Bose-Einstein

Condensates are when the particles in the system begin to act as waves, and all become one super wave.

By cooling down particles to *almost* the lowest temperature possible, where atoms do not vibrate or have any energy (absolute zero), we can create a state of matter which follows quantum rules. Once cooled to temperatures even colder than the lowest in space, the particles do not have any free energy to move about so they all are still and they eventually fall into the same quantum state. These BECs are made from bosons (a type of particle) that turn from particles to waves. Each and every boson in the system acts like a wave, it can be thought that particles are simply 'packets of energy' which can be presented as a wave. As you cool the material down further, the length of these waves increase till they overlap and eventually can be thought of as a singular wave. This one wave is sometimes called a 'super atom'. When the atoms have no energy, they clump together. It's like when steam collects to form a water droplet on the lid when you're making rice. So this matter can *only* be created with bosons and this is because they don't mind being in the same state so they disobey Pauli's Exclusion Principle (which says that atoms can't be in the same state).



This scary looking image is simply showing the states of all the atoms in the material as it cools. The flat bit on the left shows the lowest energy states of the atoms but the image in the middle and right are showing that all the particles are in one state, that's why there's just one giant peak.

They also have strange properties, but I can't find much on the internet. However, I do have some uses for BECs that can happen in the future. Before I elaborate on that, I have another interesting bit of information - BECs are related to superfluidity (a fluid that can flow without any resistance), supersolids (a strange state of matter that has the crystalline structure of a solid, while flowing like a liquid) and superconductors (materials with zero electrical resistance but there's an article on them below). A lot of 'super'. Though possibly in the future, we could make atomic lasers, lasers that don't use light but atoms… We could also make more accurate atomic clocks, and find better ways to make integrated circuits. But what's fascinating is that the speed of light is significantly decreased when travelling through a BEC. Light can travel 300000000m per second but in a BEC it's slowed to just 17 metres per second. An astonishing reduction. Light pulses can be stored in these materials and later released unchanged and ths shows amazing applications for quantum computing, telecommunications and optical storage.

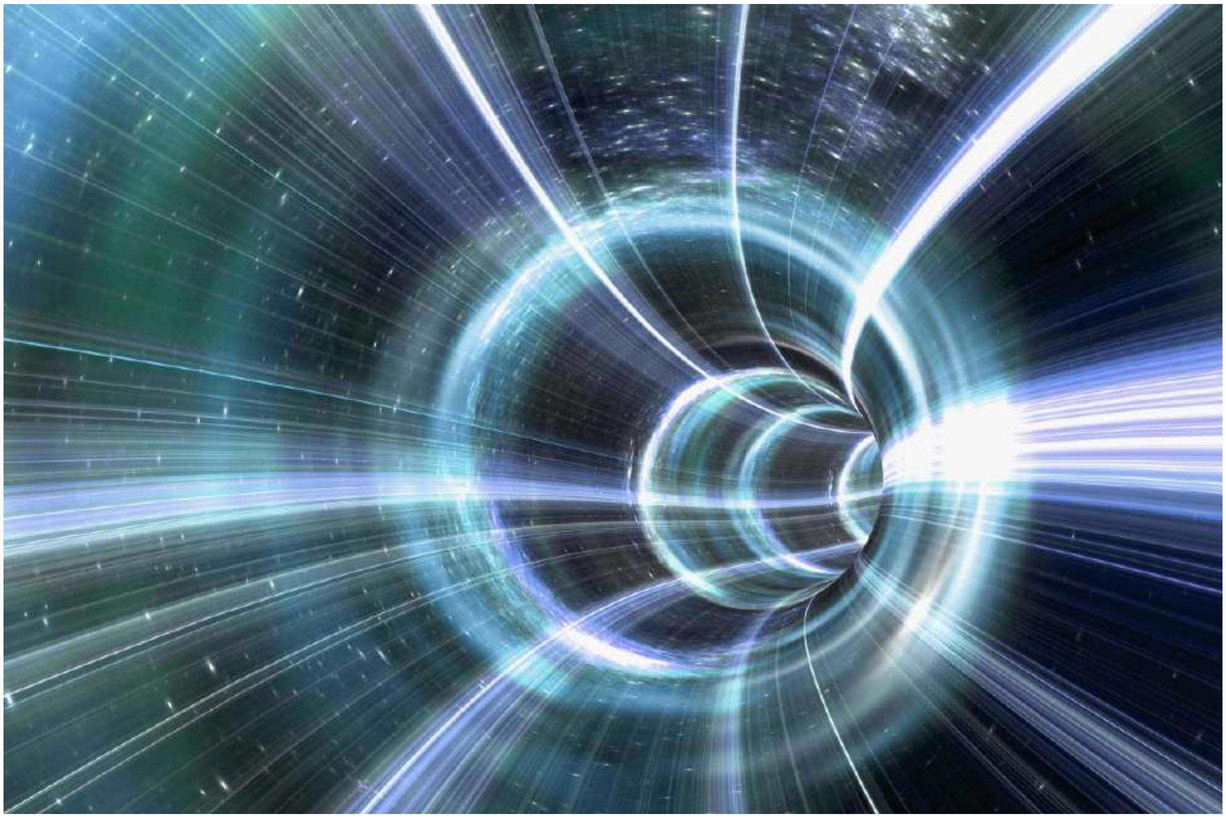
There aren't many resources to do research on Bose Einstein Condensates - that I can understand anyway - but here's what I used:

https://www.britannica.com/science/Bose-Einstein-condensate
https://www.pnas.org/content/114/23/5766
https://www.youtube.com/watch?v=Vv_ED4F1tAk
https://sciencing.com/what-is-a-diatomic-molecule-13712153.html
https://physicsworld.com/a/bose-einstein-condensation/

I was simply interested in the theory behind Bose Einstein Condensates but at the moment there aren't that many properties or uses that we know about for them since they're such delicate materials. But hopefully in the future we can actually do something, till then stay tuned for more theoretical physics articles from me :)

~ Vanshika

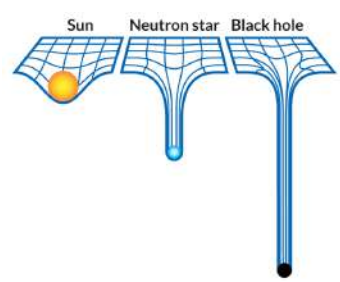
# Time Dilation and Time Travel



We live a life governed by time. It defines us as human beings. Not only are we aware of its passing, we consciously make use of it to organise our lives in the present. We use it to remember things we did in the past. We use it to plan what we want to do in the future. Even though it is always changing, its pace is a comforting constant to us. It's steady, it's predictable, you can decide what you want to do with it. So if it's a constant, why does the phrase 'time is relative' exist?

Because, quite simply, it is not a constant.

Time, it transpires, does not exist independently. According to Einstein's theory of general relativity, it is intrinsically wrapped around space, with the two being joined together to form a fabric that permeates the entire Universe: 'spacetime'. This fabric is four-dimensional, with the dimension of time being added to the three dimensions of space. It is flat when empty but can be bent by mass and energy. Ever seen those diagrams that depict how different objects warp the space around them? As you can see in the image to the right, the more massive the object, the bigger the bend due to a larger



gravitational force. This effect is called ‘gravitational time dilation’. A larger gravitational force means that time passes more slowly. Something rather interesting about this is that, since everyone has a different mass, we all experience time slightly differently. It’s a tiny, negligible difference, but still extremely strange to think about. It also means that you would age slower on the Sun than you would on Earth.

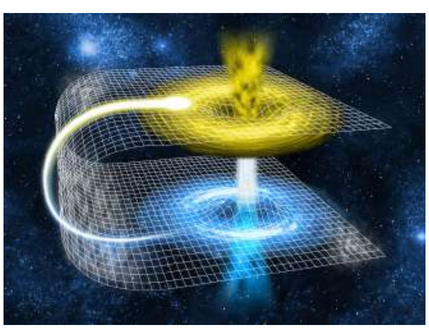
But it gets even more difficult to wrap your head around once you consider this: the faster an object is moving through space, the slower it is moving through time. I’ll use a well-known example to explain this one. Say you have a set of identical twins. One travels away in a rocket at the speed of light, whilst the other remains on Earth. The twin in the rocket returns only a few years older, but will find to their dismay that their counterpart has aged a far more significant amount. Of course, we have no way of actually testing this scenario, but what we have managed to do is launch an atomic clock into space, with an identical one remaining here on Earth. The effects of gravity are smaller up in space, so the clock in space returned running just slightly behind its Earthern double. This concept is called ‘relative velocity time dilation’. These two phenomena are not mutually exclusive, and can occur simultaneously.

So, there you have it. Those are the two main concepts in the theory of time dilation. But this wouldn’t feel like an authentic article to me unless I decided to add something mind bending, so I’m going to steer the direction of this article into dangerous territory: is time travel possible?

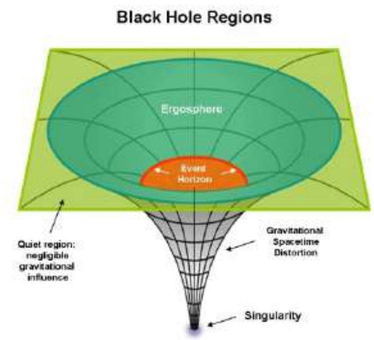
Well, hypothetically, yes. There are two main ways that it could be achieved. The first solution would be to move faster than light, breaking the cosmic speed limit. This probably wouldn’t work, though, since an object travelling that quickly would need infinite mass.

Option two is a much more complex idea: wormhole theory. According to the theory of general relativity, the existence of wormholes is plausible. But what exactly are they?

Imagine spacetime as a flat, impressionable sheet of paper, which you then fold. Wormholes, composed of an exotic matter yet to be discovered, could possibly connect these two halves via a short tunnel that would allow you to traverse across it instantly, faster than the speed of light, and end up in a very distant part of the universe, potentially at a different period of its existence.



Wormholes also come in a few kinds. The first is called an Einstein-Rosen bridge, and involves black holes. How might this work?




Firstly, we know that mass has a warping effect on spacetime. For example, truly giant stars like UY Scuti (a red hypergiant 30 times more massive than our Sun) and the Pistol Star (a blue hypergiant 100 times more massive than our Sun) make a mess of spacetime around them. But black holes have another feature that allows them to take this one step further. The denser an object is, the more it bends spacetime around it. Black holes are the ultimate example of this, because they literally form from the collapse of spacetime due to their incredibly high density, thus creating strange blips in the fabric of the universe. They are regions where gravity is so strong that nothing can escape them, including light. Time passes immensely slowly around them. If you went and stood in front of one, you would seemingly see the universe beyond you accelerate, whilst someone observing you from far away would think that you were moving in slow motion. If you were then to return to Earth, you would find that perhaps eons would have passed, and your loved ones and their progeny would be long gone.

To take this back to Einstein-Rosen bridges, think about what black holes are notorious for – consuming anything that crosses their path through their event horizon, which will then end up in their 'singularity', an extremely dense point at their core. Or will it?

The theory goes that the matter pulled in by a black hole may not end up residing in the singularity. Instead, it is speculated that there could be another side of the event horizon, which leads to an exact mirror image of our universe. Here, time would move backwards. Whilst the black hole on our side of the universe would be constantly pulling in matter, this would all be spewed out on the other side by a 'white hole'. This would be a great idea – except Einstein-Rosen bridges are crimped shut in the middle due to the black hole's huge gravitational forces, and thus impassable. In addition, it would take an infinite amount of time to even reach the middle.

But thanks to string theory, there could be another type of wormhole – the traversable kind. Now, to my immense regret, the free time of a sixth former is woefully limited, and I will not be able to discuss the beautiful thing that is string theory in this article. However, if you're interested, Vanny has written a brilliant article about it in a previous edition of our newsletter that I would definitely recommend reading.

If string theory is really an accurate model for the universe, there could be countless wormholes scattered around our universe already, created by tiny quantum fluctuations that would be dwarfed in size by atoms and could be used for time travel, with ‘cosmic threads’ woven through them. Almost straight after the Big Bang, the ends of these miniscule, ancient wormholes were pulled apart, spreading them throughout the universe. That means they could be out there, just waiting to be discovered. They would resemble black holes in that they would also be observed pulling in matter, which makes some physicists believe that supermassive black holes at the centres of galaxies could, in fact, be wormholes.

But there are several flaws in wormhole theory. Wormholes are, by nature, extremely unstable. Particles entering the structure would cause fluctuations, making it collapse in on itself. For this reason, human travel through a wormhole would be extremely difficult unless it was on a supermassive scale. Additionally, a wormhole’s existence would require negative mass and energy. Negative energy would be able to keep the structure from collapsing when objects passed through. Tiny amounts of negative mass and energy have been made in the laboratory through the Casimir Effect, but there is no evidence to suggest that there are objects in the universe that have these exotic properties. Another idea that has been proposed by some theoretical physicists like Steven Hawking is that the universe might enforce ‘chronology protection’ and destroy any wormhole close to becoming a time travel portal through vacuum fluctuations.

At the end of the day, what we know for certain about wormholes is pitifully little. In fact, we don’t even know for sure if they exist, or if they could even exist. Most of what I’ve explained is pure speculation and theories which are constantly subject to re-evaluation as we discover more. To me, theoretical physics is one of the most interesting fields in physics, simply because there is everything left to discover. You, me or anyone could be the one to find something that revolutionises the way we look at our universe.

The takeaway from this article: next time your teacher asks you why you haven’t completed your homework for four weeks, simply tell them that time is relative.

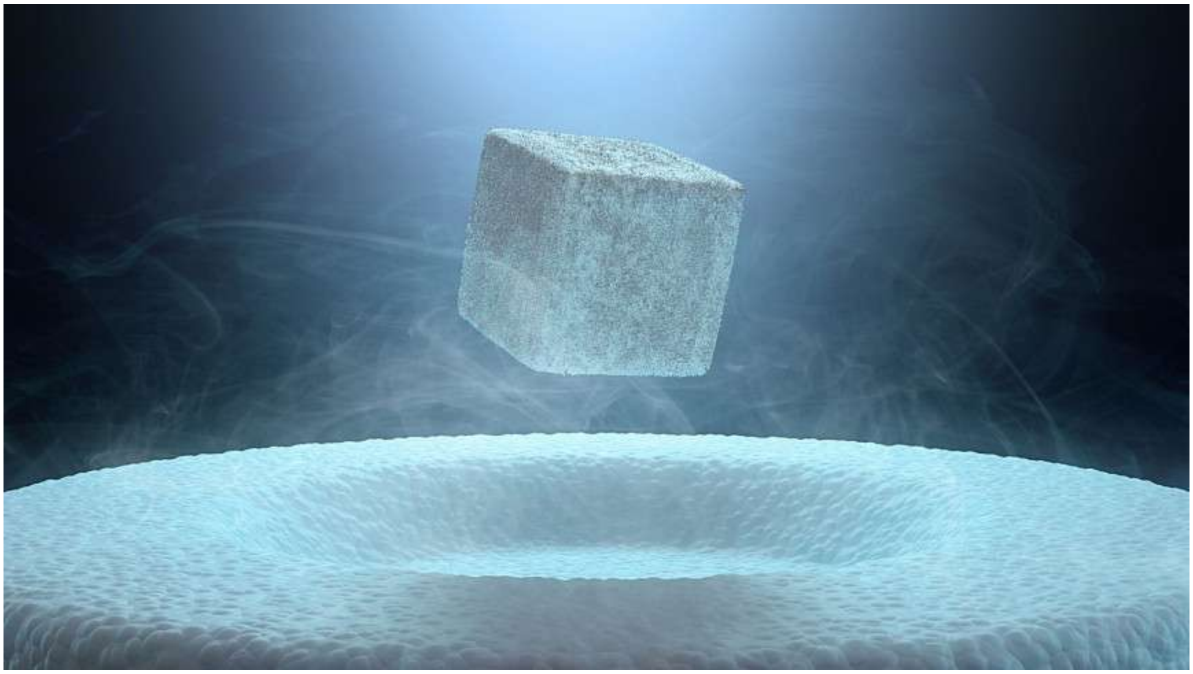
There are so many other things I wanted to write about, but I don’t, unfortunately, have the time in my life to put together a research paper, tempting as that is. However, I hope that this article is a good starting point if you want to delve further into the realms of theoretical physics (which would definitely be worth it). Thanks for reading, and look forward to the next edition of the physics newsletter :)

~ Maheen

Sources (yes, a whole page of them):


- https://www.businessinsider.com/do-astronauts-age-slower-than-people-on-earth-2015-8?r=US&IR=T#:~:text=We%20all%20measure%20our%20experience,warped%20by%20matter%20and%20energy.&text=That's%20why%20time%20passes%20slower,where%20the%20gravity%20is%20stronger
- https://en.wikipedia.org/wiki/Time_dilation
- https://www.quantamagazine.org/does-time-really-flow-new-clues-come-from-a-century-old-approach-to-math-20200407/
- https://www.nature.com/articles/d41586-018-04558-7
- https://www.smithsonianmag.com/smart-news/our-continued-existence-means-other-dimensions-are-probably-super-tiny-180970487/#:~:text=The%20world%20as%20we%20know,and%20one%20dimension%20of%20time
- https://www.space.com/17661-theory-general-relativity.html
- https://en.wikipedia.org/wiki/Theory_of_relativity
- https://www.livescience.com/65448-how-to-detect-time-warp.html#:~:text=With%20masses%20billions%20of%20times,compared%20to%20an%20outside%20observer.
- https://www.space.com/20881-wormholes.html
- https://www.space.com/40716-time-travel-science-fiction-reality.html
- https://en.wikipedia.org/wiki/Wormhole#:~:text=Wormholes%20connect%20two%20points%20in,one%20of%20its%20two%20mouths.
- https://www.sciencedaily.com/releases/2019/04/190415090853.htm
- https://www.npl.washington.edu/av/altvw103.html#:~:text=Wormholes%20have%20a%20strong%20tendency,matter%22%20objects%20with%20negative%20masses.
- https://blog.scienceborealis.ca/time-travel-is-possible-but-its-a-one-way-ticket/
- https://www.dummies.com/education/science/physics/string-theory-problems-with-wormholes/#:~:text=The%20problem%20with%20using%20wormholes,that%20they%20are%20inherently%20unstable.&text=There%20are%20theories%20that%20a,of%20space%20is%20actually%20negative
- https://www.newsweek.com/time-travel-possible-wormhole-black-hole-astrophysicist-715038
- https://phys.org/news/2017-04-physicists-negative-mass.html
- https://www.youtube.com/watch?v=QqsLTNkzvaY ('The Ultimate Guide to Black Holes)
- https://www.youtube.com/watch?v=9P6rdqiybaw (Wormholes Explained – Breaking Spacetime)
- https://www.youtube.com/watch?v=yuD34tEpRFw (Time Dilation – Einstein's Theory of Relativity Explained)

# Superconductivity



**What is Superconductivity?**
It is the phenomenon where a charge moves through a material without resistance. In theory this allows for electrical energy to be transferred between two points with 100% efficiency, losing no energy as thermal. In a standard circuit, power is dissipated at each component in the circuit and this electrical power is converted into thermal energy, therefore there is no possibility for a circuit to have perfect efficiency. So superconductors are basically materials with no resistance at all.

**Why are superconducting materials important?**
As they have perfect efficiency, if incorporated into our electronics and power grids, huge amounts of energy would be able to be saved. This would mean that we would be able to minimise circuit space, allowing us to pack more circuits into a limited amount of space. However, at the moment, superconductivity only works at temperatures near absolute zero ( 0 Kelvin ) where atoms are frozen to the point where they cannot move. Therefore incorporating superconductive materials into our daily lives would actually result in more energy being used than being saved. However, room temperature superconductors is an area of research that is gaining more attention. Hopefully in the future, a solution to this conundrum can be found!

**How do superconductors work?**

When certain compounds, such as mercury and lead, are cooled to near absolute zero (the transition temperature), they become superconductors. The Meissner effect can be observed, where the compound expels its magnetic field, losing its resistance to the flow of electrical currents and making it ideal to conduct electricity. The temperature is so low, that scientists need to use liquid helium which is quite expensive when used in large quantities. As there is no resistance, the charge is able to flow freely.

**Modern day uses:**

There have been an increasing number of applications of superconductors in recent times.

- Magnetic levitation in trains
- Magnetic resonance imaging - MRI
- Synchrotrons and cyclotrons - for use in particle colliders

The most efficient and known use is for magnetic levitation of trains which is seen everyday in places like Japan. In 1999, the Yamanashi MLX01 MagLev test vehicle achieved a speed of 343 miles per hour. Maglev trains work by using superconductive magnets, where the train 'floats' above these. Friction is completely eliminated and thermal energy does not dissipate as wasted energy, allowing the train to reach next level high speeds. In 2015 a Japanese maglev train reached speeds of 603 km/h (375 mph).

- If you wanna see maglev trains go skRRt skRRt here's a link: https://www.youtube.com/watch?v=8x8Vf8UtElQ

MRI was developed in the 1940's and is a technique that allows doctors to see what is happening inside the body without directly performing surgery. Conventional magnets were used, until superconductive magnets proved more effective as they are smaller and more efficient. The magnets are attached to the sliding table on which the patient is laid down for an MRI scan.

Particle colliders, such as the Large Hadron Collider in Cern, accelerate particles (electrons, positrons etc). Particles are maintained in their orbit through magnetic fields. As the speed of these accelerating particles increases, a stronger magnetic field is needed. Since there is no resistance to stop the flow of current and the superconductor does not heat up, it can carry far stronger electrical currents than "normal" or resistive conductors. A coil made from superconducting material can produce stronger magnetic fields than resistive electromagnets, which is what used to be used in colliders.


**Room-temperature superconductors!?**

Cutting-edge research in the field of particle physics, has led to materials being able to become superconductors at relatively warm temperatures. A compound made of sulphur and hydrogen can conduct electricity without resistance at record temperatures of -70 degrees ( 203 Kelvin ). Hopefully more research in this field will result in a time where we are able to carry superconductors in our pockets, like Richard Greene ,a physics professor at the University of Maryland, suggests: “If you had a room temperature superconductor in your pocket, you then hope there would be some very interesting applications that would come out of this.”

- https://blog.bulgin.com/blog/mri-how-does-it-work
- http://www.chm.bris.ac.uk/webprojects2000/igrant/uses.html
- https://www.insidescience.org/video/superconductors-powering-our-future
- https://www.youtube.com/watch?v=kgvLxlf_O1M
- https://www.youtube.com/watch?v=GGnzB9BqtIc
- https://www.sciencemag.org/news/2020/10/after-decades-room-temperature-superconductivity-achieved
- https://www.evilmadscientist.com/2012/basics-power-dissipation-and-electronic-components/


~ Kavya