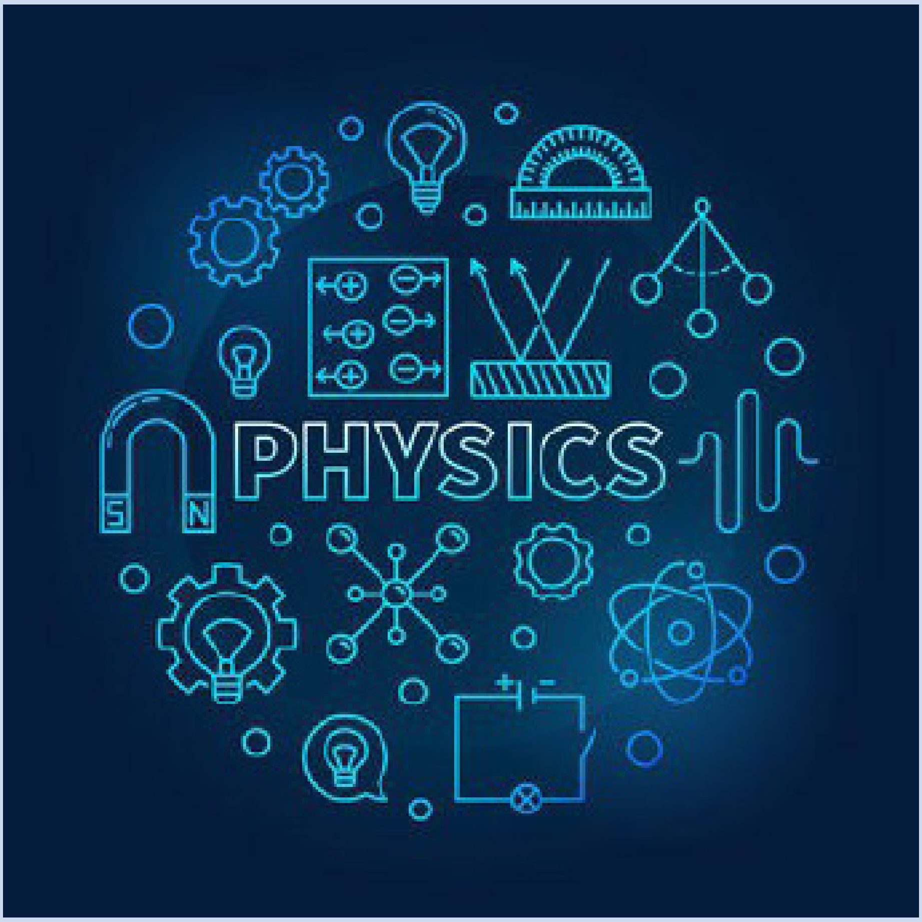
Physics A Level Essays 2021-2022



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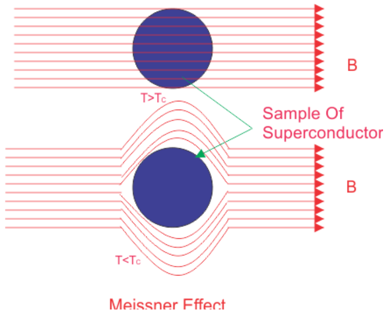
Superconductivity and its Applications

Modern science defines superconductivity as “the property shown by some materials to conduct electricity without electrical resistance”[i]. This concept has been utilised within different areas of science including, but not limited to, particle accelerators, MRI scanners and transport. Throughout this report, I will be exploring the applications of superconductivity in greater detail.

Superconductivity was originally discovered in 1911 by Dutch physicist Heike Kamerlingh Onnes who found that mercury wire lost all resistance at 4.2K. In the following years other metals such as tin and lead were found to become superconductors at low temperatures (3.8K and 7.2K respectively). In the 1950s US physicists John Bardeen, Leon Cooper (who interestingly was the inspiration for the names of two characters in ‘The Big Bang Theory’ in honour of his 1972 Nobel Prize) and John Robert Schrieffer explained this low-temperature superconductivity using quantum mechanics. They provided the explanation that it occurs when conducting electrons form Cooper-pairs which use quantum properties to evade the normal barriers to their free movement through a solid. Cooper-pairs are caused by the influence of phonons[i] – “the elementary excitation in the quantum mechanical treatment of vibrations in a crystal lattice”[ii]. At higher temperatures the vibrations are disrupted, causing them to lose their superconductive ability. In the late 1980s and early 1990s it was discovered that copper-oxide superconductors can work at temperatures up to 133K which is much higher than the superconductors previously found, meaning that they only need liquid nitrogen to cool them down to the required temperature for their superconducting properties to show.[i]

There are two types of superconductors: Type-I and Type-II. Type-I (low temperature/conventional) superconductors “lose their superconductivity very easily […] when placed in the external magnetic field” whereas Type-II (high temperature) superconductors “lose their superconductivity gradually […] when placed in the external magnetic field”[iii]. There are some main differences between the two types of superconductors. For example, Type-I superconductors have a low critical temperature (usually between 0K and 10K) whereas Type-II superconductors have a higher critical temperature which is typically greater than 10K[iv]. The “critical temperature of a superconducting material is the temperature at which the material changes from normal conducting state to superconducting state”[v]. Similarly, Type-I superconductors also have a low Critical magnetic field of between 0.0000049T to 1T but Type-II superconductors have a higher Critical magnetic field of greater than 1T[iv]. When the magnetic field increases beyond a particular value, the superconducting state of a superconductor will break, and the material will start behaving like an ordinary conductor. This certain value of magnetic field is called the Critical magnetic field[v]. Another slight difference is that Type-I superconductors perfectly obey the

Meissner effect (magnetic field cannot penetrate inside the material) whilst Type-II superconductors only partly obey the Meissner effect (magnetic field can penetrate inside the material)[iv].



The phenomenon of the Meissner effect was discovered from experiments by German physicists W. Hans Meissner and Robert Oshsenfeld in 1933. They found that superconductors are perfect diamagnetic materials. When a superconductor is placed in a magnetic field below the critical temperature it will expel the magnetic flux out of its body so the magnetic field cannot pass through the conductor. The Meissner effect is extremely useful as it can be used to easily tell when a material is superconducting below a certain temperature. A small magnet can be used to repel heavy superconductors using a levitation/suspension effect which can also be used for frictionless and fast transport systems[iii].

One use of the Meissner effect is a fairly new form of personal transport – hoverboards. Lexus have created a hoverboard which is constructed from an insulating core containing high temperature superconducting blocks that are surrounded by liquid nitrogen to cool them to the required temperature of 76K. A track made of permanent magnets causes the board to hover because when it is cold enough, the track's magnetic flux lines are 'pinned' into place[vi]. Currently the boards are still in prototype phase as it is difficult to keep them cold for a long period of time. Scientists have recently found a way to create room temperature superconductors, but it was only a tiny sample. Once an easier way to make room temperature superconductors is found, the hoverboards will be significantly easier to manufacture and use[vii].

Another form of transport using the Meissner effect is the Maglev train (short for magnetic levitation). According to both The Mysterious World[viii] and Research Insider[ix], the fastest train in the world is the L0 Series Maglev in Japan which can travel up to 375 mph. Maglev trains were originally conceptualised by Robert Goddard and Emilie Bachelet and have been available for public use since 1984. These trains use electrodynamic suspension systems (EDS) which use magnetised coils to repel the charge of superconducting magnets on the undercarriage of the train, causing it to levitate between 1 to 10 centimetres above the ground. Despite having to overcome air resistance, Maglev trains can move so fast due to the elimination of friction from no train wheels being in contact with a track (once the train moves faster than roughly 62 mph) and can mean that they can travel about twice as fast as conventional trains. As well as additional speed, the lack of friction also reduces the cost to operate and maintain Maglev trains because the parts do not wear out as quickly and means the trains are very quiet. Other advantages to Maglev trains include producing little to no air pollution and having a design that makes derailment very unlikely. Unfortunately, these trains require completely new infrastructure so are unlikely to take over normal trains anytime soon[x].

Aside from transport, superconducting magnets are also widely used in MRI (Magnetic Resonance Imaging) scanners. The magnet coils produce a large and uniform magnetic field inside the patient's body which line up the protons so they face the same direction. Short bursts of radio waves are then used to disrupt the protons, allowing them to be picked up by receivers. MRI scanners are vital in the medical field as they help to distinguish between the various types of tissue in the body allowing them to examine almost any part of the body for problems such as inflammation, tumours, or torn ligaments[xi].

According to US Energy Information Agency documents, resistance of transmission lines is causing roughly 6 to 7% of the electricity generated in the United States to be lost before it even reaches consumers. Superconducting wires would reduce the loss of electricity, improving efficiency. The new wires would even help to reduce greenhouse gas emissions, however, due to the high cost of installing the wires and keeping them cool, it will be a long time before these are used widely for electricity transmission[xii].

Finally, superconducting magnets play a vital role in particle accelerators such as CERN's Large Hadron Collider. In collider style particle accelerators, magnets steer charged particles along counter-circulating paths so the particles can be smashed into each other at high energy. Particle colliders are now built using superconducting magnets as the high energies needed by researchers are not attainable without the high magnetic fields created by these magnets. The LHC is made of many electromagnets which produce a magnetic field using a current of 11,080 amperes and a superconducting coil which allows the high current to flow without losing any energy to electrical resistance[xiii].

In this report I have discussed what a superconductor is and how it works as well as some of the positives and negatives associated with its applications. From my research I predict that in the future, superconducting materials will play an important role in many areas of science and engineering, in particular the transport industry.

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Psychophysics

Introduction and History

The Cambridge dictionary defines a science as "the careful study of the structure and behaviour of the physical world, especially by watching, measuring, and doing experiments, and the development of theories to describe the results of these activities."[1] Now as ironic as it may be that Psychologists constantly argue that Psychology is a science and yet here, I am defining a science in my first sentence. However, regardless of subject you undertake a science is born when someone notices and then tests a trend which turns out to continue to give the same results.

In the late 1700s an astronomer Nevil Maskelyne sacked his assistant for consistently getting times incorrect by 0.8s.[2] In the early 19th century Friedrich Bessel found that people would "produce consistently different times." These observations founded the base of the need for not only Psychophysics but Experimental Psychology as well which led to the 20th century where Psychology was born and experienced rapid changes with famous names such as, Wilhelm Wundt or Sigmund Freud. The 20th century also featured not so famous names such as Ernst Weber. When learning about Psychophysics I originally had never heard of it which astonished me.

In 2008, Forster and Lavie[3] conducted a study using a completely irrelevant distractor with a goal of seeing if this would affect someone's attention. They did this during "Experiment 4" by setting up participants in front of a computer screen and then displaying stimuli on the screen and displaying completely irrelevant letters in 20% of the trials. But even so "produced interference on the current task that was of equal magnitude to that from the response-competing distractor letters." This shows just how significant distractors are in our day-today lives which effect efficiency of anyone regardless of who you are or what your job is. This becomes more significant when you realise just how many distractors are in our life which will come shortly.

Theory

To begin with we have the idea of absolute threshold which is the most subtle point at which a human can detect a stimulus' presence. An example of absolute threshold could be in PAG 6.1 "Determining Planck's constant using LEDs" as we had to find the exact point at which the threshold voltage was surpassed, and you could see the LED. When testing the absolute threshold, it can be different to tell if someone detects a stimulus or they think they detect a stimulus which means they are inclined to guess which leads to obvious issues like a lack of validity in the results of an experiment. So, to deal with this when someone's accuracy is above 50% it is seen as significant as if someone is guessing it is a coin flip where instead of it being heads or tails it is they were correct or incorrect. Furthermore, there is another concept known as the difference threshold which is how much change is needed for someone to detect a difference which is also known as 'noticeable difference.' Difference threshold is given by Weber's law which is that noticeable change is a constant proportion of change[4]. A good example to explain this is if you had two envelopes and one had one piece of paper inside of it and the other had two pieces of paper inside of it, it would be

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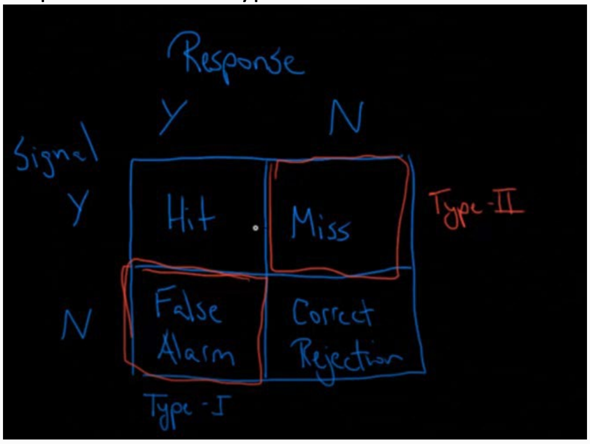
[1] https://dictionary.cambridge.org/dictionary/english/science 06/09/2022
[2] https://www.youtube.com/watch?v=GlLgFQwVQCM 19/08/2022
[3] Forster, S. and Lavie, N., 2008. Failures to ignore entirely irrelevant distractors: the role of load. *Journal of Experimental Psychology: Applied*, *14*(1), p.73.
[4] Weber, E.H., 1834. "Weber's Law of Just Noticeable Differences. Pyzetek USD Internet Sensation & Perception Laboratory. Dostopno http://apps. Usd edu/coglab/WebersLaw hmtl.

easy to tell the difference between which was the envelop with one or two pieces of paper inside of it. However, if you had a textbook that had three hundred pieces of paper in it, and you added one piece of paper you would not be able to tell a difference.

Now to talk about signal detection theory[5]. When investigating absolute there is a constant issue which is noise. In Psychophysics noise is defined as anything that interferes with your senses such as, external sounds or external lights. It is impossible to have a perfectly quiet room there will always be air molecules moving, heartbeats, or something you never realised since life is noisy. This all equates to one thing; absolute threshold is difficult to find. In a more realistic scenario, there will always be other people around, machines, and vehicles making constant distractions in life.

(A table to show all scenarios in an experiment around signal detection[6])
On the rows there are whether there was a signal present. On the columns you have the participants response. The two types of errors are different names for a false alarm (Type-I) and a miss (Type-II).



Now regardless of whether we can find absolute threshold to a fully accurate degree we can learn something about the participants trying to find absolute threshold which is response criteria. You can have two types of response criteria liberal and conservative criteria. As you can guess a liberal criteria indicates someone is prone to false alarms and conservative criteria indicates someone is prone to misses. Now at first glance this may seem insignificant, but this could apply to anything. Such as, the wind brushing your arm, a key detail that could solve a murder case, or if you hear a fly while walking.

But what about Psychophysics in relation to young children. In 2018, Manning et al[7] had a similar question so they conducted a study predicting that due to children being much less attentive than adults would preform worse than adults at estimating thresholds (a bold prediction). They used children from KS1 (6-7 years old) and KS2 (7-9 years old) and performed speed discrimination tasks. Despite the odds being against the kids, they preformed much worse than adults at these trials but as intuitive as these results may seem it the researcher stated that "some psychophysical methods are more robust to attentiveness, which has important implications for assessing the perception of children and clinical groups."

[5] Signal Detection Theory (Intro Psych Tutorial #42) 15/08/2022

[6] Signal Detection Theory (Intro Psych Tutorial #42) 15/08/2022

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Application

In 2021, Haigh et al conducted a study around Weber's law and time perception by comparing it to two separate models. They did by gathering 24 participants where 58% were female (in most Psychology most of the participants are females since a lot of participants are recruited from university classes which consist mostly of females) using social media circulation. The participants were tested individually with sessions lasting 60 to 90 minutes where they would hear two different tones and would say which of them was longer. Also, they were not allowed to use mediational (mental) processes such as, counting in their head or tapping something. There are a few models to display this relationship (Getty's model[8], Bizo's model[9]) but they found that Weber's law to this day still was the best way to describe the relationship they found.

This study should demonstrate the relevance of Weber's law and Psychophysics to this. Psychophysics was first conceptualised during the 20th century but still plays such major prevalence to how people live their lives. Going back to the first introduction where I defined science, it doesn't matter if you believe Psychology to be a science or not, it is still clear that the theory behind Psychophysics is accurate and fascinating just like any other which is what I believe science to be about. To be able to constantly inquire on new elements of your topic that you may not be able to comprehend now. But in another 100 years where will Psychophysics be which can be said about any science.

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Anamorphic Lenses – the why and the how

When were they developed?

One of the defining features of the modern movie is a “wide” look, longer than the 16:9 (approximately 1.78:1) ratio of our everyday widescreens, that gives us this cinematic feel. However, the international filmmaking community, around the 1900s, were using 35mm film that had a 4:3 aspect ratio, or approximately 1.33:1 (1).

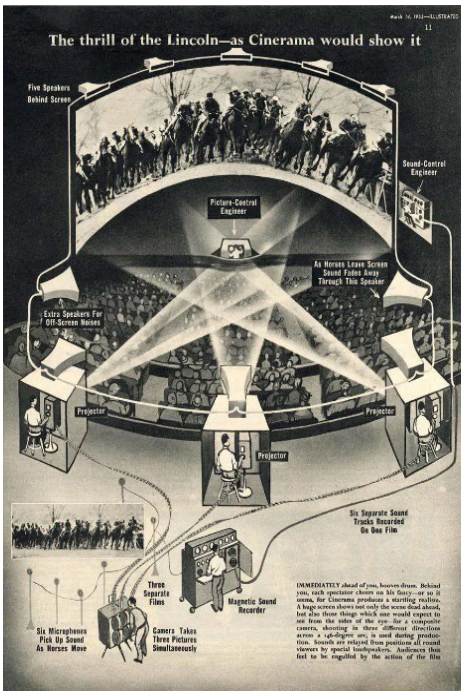

Figure 1 – Diagram of a synchronised, triple projector in a cinema, 1953 (2).

The ‘*Academy*’ aspect ratio, standardised by the Academy of Motion Picture Arts and Sciences in 1932, was a tight 1.375:1, and filmmakers began experimenting with widescreen as early as the 1920s (1). Adding black bars to the top and bottom of the frame was wasteful on film and would sacrifice resolution and brightness when projected.

Some attempts to circumvent this were introducing the *‘Fox Grandeur’* format, 70mm wide film as opposed to 35mm, while Cinerama would join three 35mm cameras together to produce an incredibly wide, panoramic image. Specially equipped cinemas, as depicted in figure 1, would have three synchronised projectors to stitch the image back together on a seamless arced screen (2).

Such implementations were far too expensive, and filmmakers sought after a solution that theatres and studios could justify the expense of – anamorphic lenses. They were developed during the first World War, in France, by Henri Chrétien, to give crews in military tanks a wider field of view, as anamorphic lenses can squeeze or stretch an image in one direction. However, in the early 1950s, 20th Century Fox saw their potential for ultra-wide “letterbox” cinematography and bought the rights (2).

The normal lens - ‘spherical’ lenses

When the word “lens” is used, this often refers to a singular, curved piece of a transparent material, but in relation to cameras, they often refer to “*compound*” lenses, multiple simple lenses (called elements) in one barrel, as just “lenses.” Spherical lenses will have their elements be shaped, as if they were sections from a sphere, and these are the assumed type of (compound) lens unless otherwise specified. Elements can be grouped together, bound by optically transparent glue. For example, the Viltrox 33mm f/1.4, that lives on my Fujifilm X-H1, has 10 elements in 9 groups that reduces chromatic aberrations with a special low-dispersion element (3). These lenses project an image onto the film/sensor without affecting the aspect ratio, trying to appear as true to life as possible.

Figure 2 - First known fisheye image recorded in 1905 using Wood’s pail apparatus (1906).

One notable example against this are fisheye lenses, very wide-angle lenses that appear to squeeze an image onto the film or sensor, producing an image with notable perspective distortion, called barrel (outwards) distortion, and most anamorphic lenses also exhibit this, to a lesser extent, due to their squeeze factor. Fisheye lenses will distort objects closer to them, curving otherwise straight leading lines.

A dioptre is a measure of optical power of a lens or curved mirror, where 1 dioptre is equivalent to one reciprocal metre, or $1m^{-1}$. A 4-dioptre lens will bring parallel rays of light to focus at ¼ of a metre, and regular windows will have an optical power of zero dioptres, neither causing light to converge or diverge. Convex lenses have a positive dioptric value, correcting for hyperopia, and concave lenses will have a negative dioptric value, used to correct for myopia.

How do anamorphic lenses work?

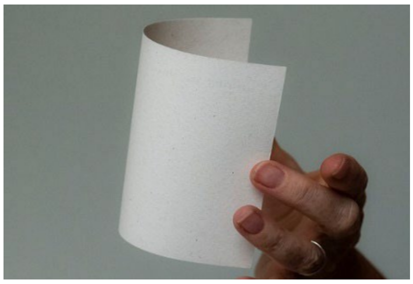

Figure 3 – a representation of what the cylindrical element looks like (4).

The word '*anamorphic'* is derived from the Greek word "*anamophoun*", meaning to transform, where anamorphic lenses will distort the incoming light, usually horizontally. This is due to a cylindrical element that is curved in only one direction, not both (4). Oriented as in figure 3, this will produce a wider horizontal field of view than vertical, and the degree of curvature this element has will decide the "squeeze factor" the anamorphic lens has. This extra element, along with the added complexity in correcting optical flaws, means anamorphics tend to be larger and heavier than their spherical counterparts, along with a lack of autofocus.

Figure 4 – a SIRUI 50mm f/1.8 1.33x squeeze factor lens (7).

Note that in figure 4, most of the elements are circular there, yet they all seem squeezed into ellipse shapes. One of the most popular anamorphic lens producers for hobbyists and amateurs is SIRUI, where most of their lenses have a 1.33x "squeeze factor" – the desqueezed image will have its horizontal aspect, of the aspect ratio be 1.33x longer, but especially for digital, the length in pixels of the corrected image will be 1.33x longer – this means the pixels would have to take on a rectangular shape, instead of their square shape, which on modern LCD monitors, is impossible as their pixels are fixed in dimension. CRTs, unlike LCDs, which due to their usage of excited phosphors and an electron gun, have no fixed pixels.

"*The Batman*" is a 2022 film shot digitally, transferred into a film negative, then to an interpositive, an "*orange-based motion picture film*", like how the 2021 film "*Dune*" was filmed and processed (5). This helped create the feeling of a cinema from the 1970s, and ARRI, one of the most popular producers of digital cinema cameras, created the "*ARRI ALFA*" (shown in Figure 5) anamorphic lenses, created specifically for "*The Batman*", redesigned and retuned to Greig Fraser's, the cinematographer, specifications – with harsh fall-off.

Figure 5 – the ARRI ALFA anamorphic lenses, a set of lenses adapted from ARRI Master anamorphic primes. (5)

Stylised fall-off

Certain elements of the cinema, from a modern viewpoint, would be technical shortcomings, are now viewed in a nostalgic light; film-like, or cinematic. Some of these are the decision to shoot at 24 frames per second, where a seemingly low rate of frame playback was chosen to save on budget, or the idea of film grain. Why would the production team behind "*The Batman"* choose to risk losing quality and resolution by transferring to a seemingly inferior medium, and then back? Film grain is a random texture found on film, due to small particles of silver found in the processing of the actual photographic celluloid – these choices are done to incorporate a vintage look, and anamorphic lenses are no different (6).

Figure 6 – A still from the 2019 thriller "Fast and Furious Presents: Hobbs and Shaw." (2)

Due to the added complexity of anamorphic lenses, versus spherical, they will generally have more elements, and therefore a higher chance to have reduced sharpness and clarity in the captured image, along with higher distortion. One prominent effect is “fall-off”, where the image sharpness, quite literally, falls off the further you get from the centre. A notable example of fall-off is figure 6, where this still image has notable distortion in the edges – parallel lines are now curved, some vignetting is present (darkening of the edges/corners of an image), almost like a fisheye lens. This stylised effect allows Jason Statham to appear as if he is warping reality, almost entrapping the audience. (2)

Bokeh rendering – how is it different?

Focus, in a lens, is paramount for any photographer, videographer, or cinematographer’s work and composition, for use in storytelling, and refers to having the subject rendered in sharp detail. The wider the aperture (opening), the shallower the depth of field is. Shown in figure 6, wide apertures also exhibit a cinematic quality, where Statham’s face is the subject of the shot – this was filmed with a wide aperture. Objects not in the plane of focus will appear blurrier, and for very out-of-focus objects, bokeh will be rendered – balls of light, where they take on the shape of the aperture. This is often just a circle, but due to the nature of aperture blades, we also often see heptagon-shaped or nonagon-shaped bokeh, from 7-bladed and 9-bladed apertures; fashioning an aperture in the shape of a question mark will also show bokeh shaped in a question mark!

Figure 7 – the same composition shot, only with a spherical vs anamorphic lens. (9)

However, when the same scene and composition is shot with an anamorphic lens, a corrected image’s bokeh takes on an oval-shape, and this also adds to the cinematic feeling – one example is the opening scene of the music video for “Fire Again” by Ashnikko (8). Despite being animated, and so having no cameras to actually work with, the opening scene begins of out of focus, with oval bokeh, and a cinemascope aspect ratio.

But why does the bokeh from anamorphic lens not return to a circle after desqueezing the image? The bokeh takes on an oval shape even after correction, due to the astigmatism present in anamorphic lenses. In spherical lenses, both vertical and horizontal planes of light will converge onto a single point, as there is no difference in image reproduction regarding vertical and horizontal. However, as anamorphic lenses squeeze an image horizontally, the horizontal plane of focus won’t converge onto the same point as the vertical plane of focus. (8)

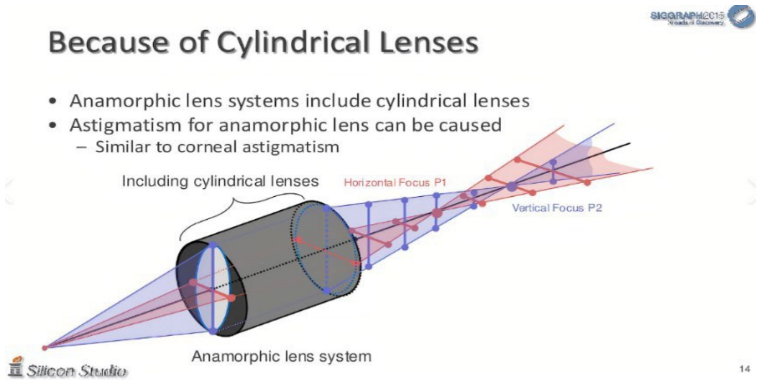

Figure 8 – a diagram showing the vertical and horizontal focuses seen in an anamorphic lens, and how they do not converge on the same point. (8)

What happens next?

Anamorphics are almost magical in their ability to distort like a fisheye in only the horizontal, yet the extra weight, size, and lack of autofocus make them almost unsuitable for budding photographers and run-and-gun videographers. They’re not for everyone, but in the hands of a talented crew, can elevate the storytelling with a vintage or cinematic feel. Adapters are available, to place atop spherical lenses, that contain the cylindrical element. However, by adding in another element, they optically perform worse than native anamorphic lenses, and often cost more than the lenses themselves.

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Could physics end climate change for good?

Before delving into this controversial question, we must first understand the possible causes for climate change, for example, are fossil fuels to blame, is there a hole in the ozone layer? We need to understand what is truly going on before discussing theoretical solutions to the issues prevalent in the world today.

What is climate change?

Climate change, as stated by the United Nations, "refers to long-term shifts in temperatures and weather patterns. These shifts may be natural, such as through variations in the solar cycle. But since the 1800s, human activities have been the main driver of climate change, primarily due to burning fossil fuels like coal, oil and gas." [1]. What this means is over the centuries the earth has gone through many major temperature shifts that were caused by natural events. One such events are what's known as solar cycles [2] these are downturns in solar activity which leads to cooling of the earth, sometimes for centuries at a time, these are called "grand solar minima". Grand solar minima occur when there are "peaks of several solar cycles in a row show less than average intensity" [3]. In severe cases this can reduce the overall temperature of the earth. However, in recent years natural causes are not to fault for the possible 1-5 °C rise in the UK temperature by [4]. For this we must turn to the steady rise in fossil fuels.

Fossil fuels

Fossil fuels are sources of energy derived from fossilized and buried remains of plants and animals that lived millions of years ago, because of their natural beginnings they have a very high carbon content [5]. From this carbon content you can draw out hydrocarbons to produce crude oil via a process called fractional distillation. During this process crude oil is pumped into the bottom of a distillation tower, where the oil is then heated. The heating allows the trapped hydrocarbons to evaporate out of the oil and then condensate at different heights in the distillation tower, those with higher densities stay in the lower layers while lower densities raise to the top. It is then possible to collect the various densities of hydrocarbons and process them into usable products such as petrol or diesel. [7]

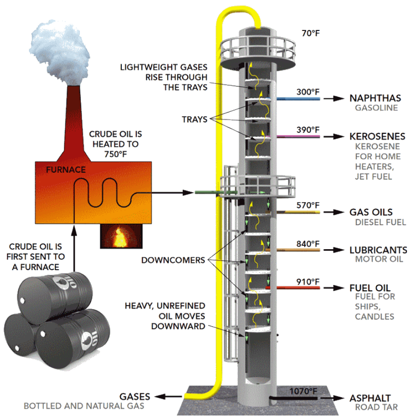

Figure 1 - Distillation Tower [6]

Why do fossil fuels have such a negative impact

When burning fossil fuels through combustion, there is a chemical process in which a substance reacts rapidly with oxygen and gives off heat [8], to produce energy and usually heat and light. (Britannica) During the combustion of fossil fuels however many harmful gasses are released, the most prevalent of which include carbon monoxide (CO), carbon dioxide ($CO2$), and sulphur dioxide ($SO2$) these are known as greenhouse gases. As we are looking at climate change, we will mostly look at carbon dioxide emissions as they are the most prevalent, in fact $CO2$ accounted for 79 percent of all US greenhouse gas emissions in 2020 due to human activities. [9]

Greenhouse gases and the greenhouse effect

As stated by the NRDC [10], the main greenhouse gases are carbon dioxide, methane, nitrous oxide, and water vapour. These work together to effectively create a protective blanket around the earth and create what is known as the greenhouse effect. This keeps heat from the sun trapped in the Earth's atmosphere and therefore heating the Earth. However, with the increased production and combustion of fossil fuels more greenhouse gases have been emitted, rising by nearly 50% from 1990 to 2021 with carbon dioxide accounting for 80% of the increase [11] and therefore contributing to the global temperature increase.

Renewable Resources and Methods

Renewable energy describes energy, which is sourced from something that won't run out, they are also natural materials and generally have a low or zero carbon footprint. This makes them an ideal source of energy when looking at ways to reduce climate change as renewable energy sources will reduce the need to burn fossil fuels [12].

Commonly used renewable energy sources

Wind – Wind farms are installed in both offshore and onshore locations. They generate electricity by utilizing the kinetic energy from the spinning blades to turn a driveshaft and a gearbox which is linked to a generator. The energy produced by the generator is then stepped-up to a higher voltage and fed into the national grid. [12]

Solar – Solar energy utilises the photovoltaic effect [12] to produce energy by making the solar cells out of materials which absorb photons of light and release electrons which can be captured which results in an electric field which can be used as electricity [13]

Hydroelectric – Energy from this method is produced via using water to turn underwater turbines which produced electricity through generators, similar to wind turbines. Hydro power can be harvested from places such as water dams as well as harnessing energy through kinetic energy produced by wave and tidal energy using similar technology. [12]

Bioenergy – Energy is harvested this way using organic matter as a fuel source. Even though they produce carbon dioxide during the process biomass is considered carbon neutral as the plant matter that makes it up absorbs as much CO2 as it produces. [12]

Measuring the Human race's energy harvesting capabilities

There are many ways in which the human race has devised to quantify how much of Earth's natural energy we are able to harvest. One of which is estimating how much material the Earth has left to offer before we run out entirely to then go onto research on how to synthesise said materials. However, Nikolai Kardashev theorised a scale in 1964 which analysed a civilisations technological advancement through analysis of how much energy the civilisation can produce. [14]

The Kardashev Scale

Kardashev originally proposed his scale to reason that if an alien planet could harvest more energy they are, by proxy, more technologically advanced and therefore the more powerful their transmissions will be. Thus, increasing the chance of detecting the alien race from a greater distance. When Kardashev first devised his scale, he deemed Earth not suitable for even the first category, however Carl Sagan later revised the scale, quantifying it. Sagan decided that Earth is a 0.72 civilisation, for a reference a 1.0 civilisation would be able to produce the energy equivalent to the solar energy which strikes the earth surface [14], or about 1360 watts per square metre [15]. To further this, Kardashev proposed in his scale that there are feasibly 3 types of civilisations and that anymore would only exist in the realms of fiction. Type 1 is a civilisation with the ability to "harness all the energy that is available from a neighbouring star", a type 2 civilisation would be able to "harness the power of the star (not merely transforming starlight into energy. Bur controlling the star)". Kardashev believed that once a civilisation had reached type 2 then they would have enough disposable energy to avoid an extinction event, so how did he progress his scale further than type 2? Well, he proposed a type 3 civilisation, one that could possess the knowledge of everything to do with energy, possibly even evolving into a cybernetic race. [16]

<u>How could Earth become a type 1 civilisation?</u>

In the 1960's Freeman J. Dyson (physicist and astronomer) proposed the idea of what is now known as a Dyson sphere. Dyson spheres are theoretical megastructures that are built around a solar systems star with the intention to harvest as much solar energy as possible and transmit it back to the planet/s. Freeman originally thought of this concept more as a swarm of solar shades independently orbiting the star, rather than a solid sphere [17]. These swarms of solar panels and mirrors are also thought to be a new way to look for other signs of intelligent life in the universe by searching for point sources of infrared radiation [18]. The main issue with Dyson spheres is the sheer volume of resources we would have to mine from the Earth just to build the technology and megastructure itself. It would need a diameter greater than that of the sun, meaning at a minimum the diameter would need to be 1.4 million km [19]. Therefore, it may not be possible for Earth to progress further than it has without sourcing materials from elsewhere in the solar system, which we also don't yet have the resources for.

<u>Could we populate other planets?</u>

Seeing as it is currently not possible nor plausible to build a Dyson sphere around our mother star we could begin to look at inhabiting other planets close to our own, this has it's own unique set of issues as humans have evolved specifically for the conditions and atmosphere of earth meaning we would have to emulate it on another planet or look for a planet comparable to ours. This becomes a very difficult task as researchers are looking for Earth-like planets in the habitable zones of other stars, habitable zones being the distance from a star where water could exist on the surface of a planet without being to hot or cold [20] To find an estimate of the probability of finding a habitable planet we can look at the Drake equation. This is an equation devised by Frank Drake in 1961 with the goal of estimating how many intelligent lifeforms could exist and therefore a rough estimate of planets in the 'habitable zone' from their star [21]. However, there are so many parameters that are included in the equation that it becomes impossible to find accurate answers or estimates and therefore the overall answer the formula produces aren't credible, for all we know we are alone in the universe with no other remotely habitable planets.

$$N = R_* \cdot f_P \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

N = number of civilizations with which humans could communicate
R_* = mean rate of star formation
f_P = fraction of stars that have planets
n_e = mean number of planets that could support life per star with planets
f_l = fraction of life-supporting planets that develop life
f_i = fraction of planets with life where life develops intelligence
f_c = fraction of intelligent civilizations that develop communication
L = mean length of time that civilizations can communicate

Figure 2 / The Drake equation

To conclude, Earth is suffering majorly from how the human race has misused and exploited the materials available to us in the vain attempts to be better at the expense of the Earth's biosphere. The human race might be too late to engineer our way out of this situation but hopefully, by continuing to bring carbon emissions down and by using renewable resources we will be able to buy enough time to be able to engineer a solution.

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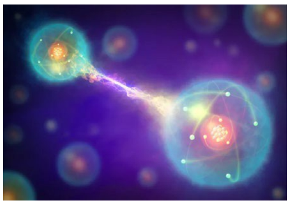
What does Quantum Entanglement mean for modern science?

In the last thirty years, radical discoveries of communication and new computational models have developed the area of quantum information by providing more efficient performances than their classical counterparts[1]. Modern science has been transformed by quantum dense-coding (DC) and the transfer of quantum states[2] – entanglement is the nexus between these findings. Indeed, as Austrian physicist Erwin Schrödinger recognised, “entanglement is the essential feature” of quantum mechanics[3]. In this report, we first define entanglement before briefly discussing its discovery. We then review methods of entangling single particles or pairs of photons in order to consider the modern uses of quantum entanglement, as well as the problematic implications of this phenomenon[i].

Definition of entanglement

Firstly, if two particles are entangled, their properties must be identical (in the case of spin[ii], these will be opposite). If one particle is a wave, its partner will be, too. The most useful element of this correlation is that it is unaffected by vast distances because once particles become entangled, they share a unified state[4] – this opens new avenues for long-distance communication. Xie Chen, professor of theoretical physics at Caltech, argues that “when particles are entangled, it is as if they are born that way, like twins”[iii] because “even though they might be separated at birth, [they will] still look the same [and] grow up having a lot of personality traits that are similar to each other”[5]. However, one of the challenges posed by entanglement is that we cannot dictate what properties are identical. For instance, an electron can be forced to take on a spin by passing it through a detector, but we cannot control whether it takes an ‘up’ or ‘down’ spin – this is entirely random and unpredictable[4]. To demonstrate[6], suppose Alice (A) and Bob (B) are in two distant locations; A prepares a quantum state, $|\Psi_A\rangle$, belonging to a complex Hilbert space[iv], $\mathbb{C}_A$, and Bob prepares a quantum state, $|\Psi_B\rangle$, in $\mathbb{C}_B$, both through local operations. The joint state between A and B is known as a product state. However, entangled states cannot be prepared through local operations, so a state is said to be entangled if

$$|\Phi_{AB}\rangle \neq |\Psi_A\rangle \otimes |\Psi_B\rangle.$$



Method – Teach me how to (en)tangle[3,v]

1. Cool particles down.
2. Place them very close together.
3. Their quantum states will overlap (representing uncertainty in position).
4. When it is impossible to distinguish one particle from the other, they are in a unified state.

However, it is also possible for entangled particles to be automatically produced by subatomic processes, like nuclear decay, or lasers, which use spontaneous parametric down-conversion[vi]. NASA has also split a single photon and generated an entangled pair in the process, as well as mixing pairs of photons in fibre-optic cable[vii].

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[i] Despite the centrality of entanglement in this review, it is important to note that there will be no reference to the 2017 romantic comedy of the same name.
[ii] Spin can be defined as the angular momentum of elementary particles and atomic nuclei.
[iii] This analogy was inspired by the famous ‘Jim Twins’ separated at birth in the 1940s, who met much later in life. They led near-identical lives despite the distance between them, similar to entangled particles.
[iv] A Hilbert space is a vector space that allows lengths and angles to be defined. They are complete, allowing calculus to be used.
[v] Subheading title inspired by Cali Swag District (https://www.youtube.com/watch?v=aZglqkCRNt8).
[vi] Healy summarises SPDC effectively here: https://www.physicssayswhat.com/2017/04/25/how-to-create-entangled-photon-pairs/.
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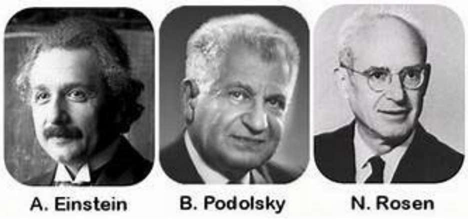
Prehistory of Quantum Entanglement[7]

In the early 20th century, physicists like Max Planck and Erwin Schrödinger were developing the fundamental ideas behind entanglement through their work on quantum mechanics. They realised that in order to adequately describe subatomic systems and processes, they needed to use a 'quantum state', which is defined as "the probability of measuring a certain property of a particle, like its position, […] the quantum state of an electron describes all the places you might find it, together with the probability of finding the electron at those places." (Sutter, 2021). Bohr's ideas of complementarity[viii] dominated the early landscape of quantum theory, but that was before Einstein challenged the uncontrollability of measurement interactions to investigate how strongly related quantum theory was to irrealism [ix]. Einstein felt that ideas like Bohr's abdicated the historical task of natural science, which was to provide knowledge independent of observers. Ironically, these ideas were based on work started by Einstein[9], showing just how subjective and uncertain the quantum world really is. This discrepancy in scientific theories resulted in the Einstein-Podolsky-Rosen (EPR) Paradox, a thought experiment heavily reliant on entanglement.

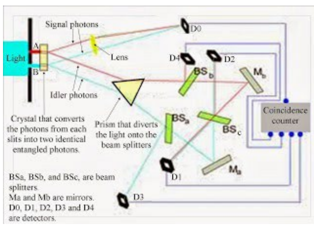


The development of the EPR Paradox

When Albert Einstein, Boris Podolsky and Nathan Rosen came together in 1935, they found that measurements of one particle automatically influence the other in that unified state, regardless of the distance between them[8,9]. Due to this, the two particles can be on opposite ends of the galaxy, and we would still have instantaneous knowledge regarding their state and measurements. The paradox arises out of the fact that this instantaneous knowledge "appears to violate the limit of the speed of light" (Sutter, 2021) – conflicting with Einstein's theory of relativity[9]. For EPR, this was evidence that quantum theory was incomplete, resulting in Einstein famously referring to the consequences of entanglement as "spooky action at a distance". Since there was no real way of experimenting this prediction at the time, it was just considered a thought experiment[x].

This paradox became the focus of discussion between Einstein and Bohr, but even professional physicists found the original version somewhat confusing due to the abstractedness of these quantum concepts – enter David Bohm, who, in 1951, modified the EPR paradox to clarify its propositions. Bohm's formulation involves an unstable particle with spin o decaying into two different particles, A and B. These particles will predictably have spin +1/2 and -1/2 (the sum of the new particles must equal zero because the initial particle had spin o[10]), though it is impossible to determine their definite state until a measurement is made, according to the Copenhagen interpretation of quantum mechanics[11]. Here, Einstein got entangled in entanglement. As soon as the spin of A is measured, we will know for sure the spin of B, suggesting that the state of the latter is somehow 'set' by the measurement of the former, but B also instantly 'knows' what spin to assume, supposedly prior to our measurement. In Einstein's mind, this clearly violated his theory of relativity.

Entanglement = Time Travel? The Quantum Eraser



However, it is this paradox that modern science draws hope from for the future of time travel. Inspired by EPR, Yoon-Ho Kim, Rong Yu, Sergei P. Kulik and Yanhua Shih conducted the Quantum Eraser experiment in 1999, reporting a delayed "choice"[12] made randomly by a photon at a beam splitter. Specifically, this experiment sent two entangled photons through a device[4]: A to a detector and B through a series of 2-way mirrors. Since photons are waves that can collapse into particles, B can become a particle if it

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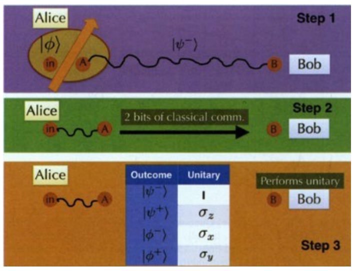
[viii] According to complementarity, when we observe an object's position, we affect its momentum, so we cannot determine both position and momentum simultaneously or precisely (the fons et origo of Schrödinger's cat).
[ix] G.S. Evans provides a more thorough explanation of irrealism in relation to modern culture here: http://www.wright.edu/~david.wilson/eng2040/whatisirrealism.pdf.
[x] Or, as Einstein popularised it, 'Gedankenexperiment'.

takes a certain path or stay a wave if it takes another path. If this is repeated and all A photons are entangled with the B photons that stayed waves, those A photons will also be seen as hitting the detector as a wave[xi], creating an interference pattern. Each A photon hit the detector before B finished its journey. It is as if A knows what path its partner particle will take and whether they will end up there as a wave or particle before B even gets there. Another theory more radically suggests the possibility that once B finishes its journey, it sends a signal back in time to let A know whether it should be a wave or a particle[4].

What ensued in modern minds is a series of rather questionable hypotheticals[4]: if we develop a way to dictate what properties quantum particles take on, then entangle the particles of one person's brain with the particles in the brain of someone in the past, then the person in the present could control the actions of the person in the past. Unfortunately, this is yet to happen.

OK, Entanglement ≠ Time Travel. Does Entanglement = Teleportation?

Firstly, it is important to note that teleported quantum information does not travel materially from A to B. What does travel materially is the message about A's measurement result, which informs B how to process the photon. This is done without carrying any information about the photon's state itself[3]. However, methods have been devised to teleport this message on a minuscule level[7]:



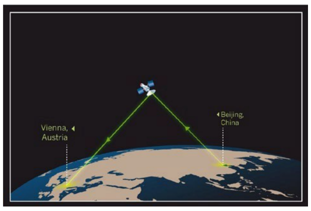
1. Sender prepares a particle to contain the information they want to send.
2. Combining quantum state with the entangled pair of particles results in the corresponding change in the other pair.
3. The receiver records the change in the entangled partner of the pair.
4. The sender must transmit the original change made to the entangled pair via normal channels[xii].
5. Receiver reconstructs the quantum state in the new location.

Sceptics complain that we can only teleport a photon's quantum state, not the actual photon, but since its quantum state is the defining characteristic, teleporting its quantum state is equivalent to teleporting the particle.

Uses of Entanglement and Challenges

Quantum networks that work through entanglement are used in cryptography, which is more secure than classical communication because any external interception would break the entanglement and be revealed when the receiver compares the traditional signal to the change in the entangled pair. For this reason, entanglement is used to generate private keys that encode messages. This has transformed modern science by making communication much safer and efficient than classical channels – it is the quantum version of how the World Wide Web works in conventional computers[5]. Perhaps the most beneficial use of entanglement is in quantum computers. Here, large numbers of particles are entangled and work together to solve complex problems. In comparison to classical computers, they are much more efficient because 10 quantum bits (qubits) can represent the same memory as 2^{10} traditional bits[7].

Another use of entanglement within modern science is in astronomy[7]. Current telescopes are limited in their resolution for larger distances, like the surfaces of distant exoplanets. However, if scientists found a way to entangle telescopes into a quantum network, "we could use the whole Earth as one big telescope with a much-improved resolution" (John Preskill, theoretical physicist at Caltech). This advancement in modern science could be the key to expanding space exploration and looking for signs of civilisation. In fact, our very planet could be closely monitored by scientists on an



[xi] A photons paired with B photons that become particles therefore hit the detector as particles.
[xii] Normal channels are those limited by the speed of light.

exoplanet that has already untangled the theory behind entanglement to create such a quantum network – the possibilities are endless.

On the other hand, modern scientists are limited in how much fun they can have with entanglement due to the delicate nature of quantum systems; entangled states can easily disappear or collapse when their surroundings change even slightly[5]. This is because particles easily become entangled with their environment in just a few microseconds or even faster, which nullifies the initial entangled state the researcher tries to investigate through a process called decoherence. This is why we cannot teleport humans – it is hard to isolate a piece of equipment, let alone a body that breathes and radiates heat. Manuel Endres summarises this struggle by saying, "You need to create a system that is entangled only with itself, not with your apparatus[5]." In quantum computing, this liability is problematic because it leads to computational errors: if the qubits become disentangled, the computer stops functioning. In an attempt to solve this conundrum, Alexei Kitaev (professor of theoretical physics at Caltech) and Preskill have devised a concept that hides the quantum information in a global entangled state. This is similar to sharing parts of a code with people living in different cities because no one has access to the complete code, making its discovery unlikelier.

Conclusion

In summation, this review has defined entanglement and briefly tracked its discovery at the beginning of the 20th century through the EPR paradox. We then discuss methods of entanglement and the consequent possibilities of teleportation of information. We report the possibilities enabled by quantum entanglement, especially in relation to communication, computation, and space exploration. However, in agreement with Bohr, true development of entanglement in the future relies on our understanding that science does not necessarily explain how the world *is*, but rather finds a way of expressing what we can *say* about the world[3] from our observable knowledge. The current value of radical experiments like teleportation thus lies in helping modern science achieve a profounder understanding of the entangled quantum world.

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What does the Higgs Boson tell us about the Big Bang?

When the Higgs Boson was discovered by CERN (Geneva, Switzerland) in its ATLAS and CMS particle detector experiments[1], it was a monumental discovery in the field of physics. The Higgs Boson, the quantum manifestation of the Higgs Field, supports the Standard Model of Particle Physics and can tell us a significant amount about the universe right from the Big Bang and possibly even into the future.

To understand the Higgs Boson, you must first understand the Standard Model. The Standard Model contains all of the fundamental particles in the universe: photons, gluons, the W and Z bosons and quarks[2]. These particles are fundamental; they cannot be broken down any further. The bosons in the Standard Model are force carriers and are essentially the quantum manifestation of their associated field from the four key forces (electromagnetic, gravitational, weak nuclear and strong nuclear force). For instance, the electromagnetic force has the photon particle, and the W and Z bosons are linked to the weak nuclear interaction. In the same way, the Higgs Boson is the quantum manifestation of the Higgs Field – an omnipresent quantum field[3]. Although the Standard Model is by no means a perfect model (as it doesn't account for gravitational force or dark energy and dark matter), the Higgs Boson does lend a lot of support to it[4].

The Higgs Boson was initially proposed after the unification of the weak and electromagnetic forces at energies about 100GeV[5] into one mathematical relationship, wherein there was the implication that fundamental particles were massless – despite this obviously not being true in nature. The Higgs Boson remedies this as Brout, Englert and Higgs suggested a mechanism that would allow for particles to get mass. It was later proved that this mechanism was real; the Higgs Boson is able to give particles their mass from interaction with the Higgs Field[6]. How this works is that, as Einstein demonstrated, $E=mc^2$ so energy gained from interacting with the omnipresent Higgs Field translated into mass gained[7]. So, initially particles would be massless and travelling at the speed of light but would acquire masses with this interaction. Furthermore, further experiments have told us the properties of the Higgs Particle, including that it has no spin. Spin is the quantum property of particles that describes the fixed angular momentum of a particle[8]. In simpler terms, spin is the 'rotation' of a particle around a given axis. Since particles do not actually rotate in the way we know it, spin describes an intrinsic property of particles. It can fall into four categories: left handedness, right handedness, up and down, and is assigned a number spin. Fermions typically have a half odd integer spin, and bosons have integer spin. This property is intriguing as the Higgs Boson is the first fundamental particle to have no spin and is thus the only scalar fundamental particle to be observed so far. In addition, the Higgs Boson is observed to be incredibly unstable and also to have no colour charge (another quantum property). All of these properties make the Higgs Boson a very unique particle – as it is unlike the remainder of the observed fundamental particles.

The Higgs mechanism was theorised in independent studies between Peter Higgs, Robert Brout and Francois Englert. In their initial studies, they proposed that something must be responsible for giving mass to the elementary particles. The LEP (Large Electron Position Collider) at CERN made the first bit of progress to proving the existence of this mechanism. The LEP determined the range of mass the Higgs Boson should be, with an estimate of over 114 GeV; this is significant as the discovered true mass is 125 GeV. The research was later passed over to the Tevatron collider at the Fermilab. This estimated masses of around 160 GeV. During the Tevatron's experiments, the Large Hadron Collider (LHC) was being produced at CERN. When the LHC was complete, scientists began experimenting for the Higgs Boson. In one of the LHC's seven particle detector experiments, called the ATLAS experiment, it was discovered that the Higgs Boson could be excluded from all masses – not including at 125 GeV. There were further experiments conducted at the CMS particle detector.

Neither the ATLAS or CMS experiments produced a strong enough data set to imply they observed the Higgs Boson, but they both had discovered masses in excess of 125 GeV[9].

The relevance that the Higgs Boson has to the Big Bang Theory is immense. The Big Bang, a theoretical (but widely accepted) explosion from a central dense point, was the beginning of the observable universe[10]. The Higgs Boson, later coined the "God Particle" to many scientists' chagrin, was credited for the Big Bang as it gave mass to the other particles and was suspected to be the "inflaton". The Inflaton is a particle with zero spin that is theorised to be behind the rapid expansion of the universe around 10^{-35} seconds after the Big Bang[11]. Despite having zero spin, there is a lot of debate if the Higgs Boson is this inflation particle. Finding out whether the Higgs Boson requires a lot of experimentation around the particle which may be difficult for CERN's LHC (Large Hadron Collider) to investigate[12]. However, the Higgs Boson can tell us a lot about the Big Bang regardless of its potential as the inflaton. For instance, it also explains the masses possessed by other fundamental particles at the time of the Big Bang.

The Higgs Boson doesn't only hold promise in explaining the Big Bang; it can also reveal a lot to us about the future of the universe. Stephen Hawking theorised that the Higgs Boson could potentially be the reason behind the universe's end in the preface to his works "Starmus". He explains how the exact energies of the Higgs Boson is coincidentally on the brink of instability. Hawking claims that the Higgs Boson may be metastable (in a state of equilibrium given that there are no small changes subject to it) at its given mass The issue with this is that it could lead to "catastrophic vacuum decay" (Hawking), which is essentially a theoretical event when the universe decays into a lower-energy state. The effect of it will be a 'bubble' expanding outwards at the speed of light, in which the interior of the 'bubble' will defy our normal physical laws. This vacuum state could alter nature as we know it, or how mass and forces operate at a fundamental level. And, Hawking points out, we would not even be aware of its arrival because of the speed at which the 'bubble' expands[13]. This idea would ultimately mean the destruction of the universe.

Even though the Higgs Boson was discovered years ago in 2012, there is still a lot more that we need to know about the particle. Many experiments around the Higgs Boson include its decay into other elementary particles. Another area of interest that the Higgs Boson provides is its supersymmetric partner. Super symmetry is the idea that every particle has not only an anti-particle but a supersymmetric partner. Super symmetry gives particle's partners a difference in spin by half and are also a generally heavier replica. In addition, there are two types of particles: fermions (a group of elementary particles including leptons and quarks) and bosons. When a particle is a fermion, it should have a boson supersymmetric partner and vice versa. So, essentially, supersymmetry should create balance. However, only one of the pair is detectable and ultimately, supersymmetry is a theory[14]. Despite this, it could still mean that a large source of experimentation for the Higgs Boson may be in discovering its supersymmetric partner.

In conclusion, the Higgs Boson can provide us with immense information about the Big Bang. It explains the introduction of mass to the W and Z bosons and other matter particles during the initial explosion billions of years ago that is responsible for the universe today, and it lends strong support to the Standard Model of Particle Physics. The Higgs Boson explains a lot about the beginning of our universe and, through further investigation, can also begin to give insight into our future.

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Meteors that impacted the earth, and when will the next one hit?

Meteorites are often portrayed as big scary rocks that could end humanity with one shot, although its somewhat true the fact is that every year, the Earth is hit by around 6100 meteors large enough to reach the ground. Most asteroids that enter the earth's atmosphere burn up before reaching the earth's surface. A lot of the time meteors struck uninhabited areas or seas, so they go unnoticed. The biggest recent meteor crash was in Russia which was in 2013 and it was named the Chelyabinsk meteor. [1] The meteor has caused around $3 million in damage and about 1000 people were injured as it hit a habited area, the meteor was about 17 meters in diameter. [1]

Asteroids are pieces of rock or debris that float around in space usually orbiting planets in their gravitational field. A meteorite is the term given to a piece of a comet or asteroid that falls into the earth's atmosphere and survives to hit the surface. There are different types of meteorites such as: stony meteorites or metallic meteorites.
Stony meteorites: "Stony meteorites, as the name implies, are made from rocky material not all that different from what's found in the ground on our planet. These objects are the most common type of meteorites and are thought to represent leftover fragments from the creation of our solar system. Such meteorites often contain organic, or carbon-containing, compounds, the molecular basis of living organisms, and sometimes even traces of water, suggesting that the ingredients for life may have originated before our world was born."[2]
Metallic meteorites: "Metallic meteorites contain mostly iron and nickel, while stony-metallic meteorites are made from both rocky and metallic material. Only around 8 percent of meteorites fall into either of these categories. Some of these meteorites originated on the moon or Mars and have therefore given scientists insights into different bodies in the solar system." [2]

Meteorites come from:
- Asteroids: majority of meteorites are fragments of shattered asteroids. Asteroids are rocky bodies found mostly in the asteroid belt, between Mars and Jupiter. [3]
- Planets: A small number of meteorites are pieces of rock from the surfaces of other planets. These fragments were likely blasted off planets when they were hit by a large asteroid or comet. [3]
- Moon: Small pieces of the Moon also sometimes reach Earth as meteorites. [3]
- Comets: Meteorites might also come from comets. Made of dust, rock and ices, comets are typically found in the outer reaches of our solar system. [3]

Over earths existence a huge amount of different size meteorites struck the earth. Roughly 66 million years ago a 7-mile-wide meteor slammed into the earth. The meteor was estimated to weight around 6.82x10^15 kilograms (6820000000000000kg). We also have an estimate for the meteor speed which was about 1000 kilometres per hour. Using p=mv we can calculate the force at which the meteor impacted the earth at. $p=6.82\times10^{15}*1\times10^{6}$,

$p=6.82x10^{21}$. Which is equivalent to 7 billion medium size nuclear bombs going off at once. It was a huge impact that left earth in harsh conditions for next couple of decades. The Chicxulub crater located in Yucatán Peninsula in Mexico, the crater has ~180km diameter and is the 2nd biggest crater in the world. [4] Majority of the meteor vapourised at the impact. After the impact it took over 30,000 years to get back to progressing state.[5]

Most dinosaurs died over 66 million years ago when the Chicxulub meteor slammed into the earth and wiped out 75% of all life on earth [5]. Life only survived in the places which did not experience much change after the impact – such as deep-water areas. The Some life had survived and evolved to cope in the harsh conditions that have developed after the impact – Right after the impact: 700mph air blast away from the impact area, tsunamis, earthquakes and fire ball radiation. [6] Months after the blast: constant fires causing acid rains and huge amounts of dust in the air covering the entire sky.[6] The dust covered sky (mainly sulphur and other rocks) [6] stopped sunlight coming through which led to no photosynthesis for a long time which contributed to extinction of most herbivore dinosaur species. They died due to a lack of sunlight which led the plants to die so they had nothing to eat. Which killed off the somehow surviving life forms. The impact of the meteor left many environmental marks which are still affecting us to the current day.

Next major meteor is said not to hit earth for another 100 years, the closest meteor that was close to hitting the earth is the 99942 Apophis. The asteroid was estimated to destroy up to several hundred kilometres around its point of impact, for scale comparison it would destroy a country like Poland and affect the surrounding countries.[7] The Apophis discovered was discovered back in 2004 and been identified as one of the most dangerous asteroids coming towards earth. The asteroid is about 340 meters across.[8] This is way bigger compared to the Chelyabinsk meteor (17 meters), the Chelyabinsk meteor caused over $3 million in damages.

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[2] - https://www.space.com/42636-meteorites.html - 20/07/2021

[3] - https://www.lpi.usra.edu/science/kring/Chicxulub/images/hi-res/EnvironmentalEffectsSummary.jpg - 23/07/2021

[4] - https://en.wikipedia.org/wiki/List_of_impact_craters_on_Earth - 23/07/2021

[5] - https://www.space.com/36239-dinosaur-killing-asteroid-strike-chicxulub-life-return.html - 23/07/2021

[6] - https://news.utexas.edu/2021/02/24/asteroid-dust-found-in-crater-closes-case-of-dinosaur-extinction/ - 24/07/2021

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Physics PAG 12 Research Report
Is Thermo-Nuclear Propulsion the Future of Deep Space Expeditions?
Michal Sobocinski

Introduction

Humanity has been launching rockets intended for space exploration for over 60 years, with the first being the Russian R-7 ICBM rocket that launched Sputnik in early-October of 1957. This repurposed ICBM rocket used liquid oxygen and kerosene. This liquid propellant mix is commonly used within chemical rockets presently (alongside other combinations such as liquid oxygen and methane). These rocket engines work by utilising Newton's Third Law of Motion which states that when object A, in this case the engine, exerts a force on object B, the air, then object B will exert an equal and opposite force on object A, causing the rocket to launch into the air (in space it follows the law of conservation of momentum). However, the space industry has been experiencing a grave issue with their liquid rockets. These rockets can have an efficiency of up to 35%[1]. As rockets depend on Newton's Third Law, the greater force, and therefore velocity, that would be liked to achieve requires more liquid propellant. This means that the volume of propellant required increases exponentially when a greater velocity needs to be achieved. This can make rockets more complicated, costly and reduce payload weights as the propellant is used to lift the payload as well as the rest of the propellant. This report aims to explore an alternative to chemical rockets, thermo-nuclear propulsion which has been researched since 1967 with the XE engine.

The Specific Impulse of an Engine

As there are numerous types of designs of propulsion engines, each with their own systems. It can be difficult to compare engines with one another to decide which is more favourable. However, most commonly, scientists and engineers compare engines based on their specific impulse (abbreviated Isp). The Isp refers to the time in seconds for one pound of propellant to deliver one pound of thrust. It can be used as an indication for engine efficiency and can be used to determine the thrust of a rocket. The engine with a higher specific impulse is more efficient as it produces more thrust for the same volume of propellant.[2] Modern chemical rockets are limited to a specific impulse of about 450 seconds. This is extremely inefficient compared to potential nuclear rockets that can have an Isp of 900 seconds (Youtube: *Documentary Tube 2018*). This means that nuclear rockets are up to 2 times as efficient as chemical rockets.

General Thrust Equation

The thrust of an engine, given mass flow rate, is given by:

$$F = \dot{m}_e V_e - \dot{m}_0 V_0$$

https://www.grc.nasa.gov/www/k-12/Virtua 1

Where **ṁ** is the mass flow rate and V is the velocity. With the sub e denoting *exit* mass flow rate and velocity and the sub 0 denoting *input* mass flow rate and velocity. Mass flow rate simply means the mass of the substance which passes through the engine nozzle per unit time[3].

[1] https://www.nasa.gov/centers/glenn/technology/Ion_Propulsion1.html (line 3-4)
[2] https://www.grc.nasa.gov/www/k-12/airplane/specimp.html (line 29-30)
[3] https://en.wikipedia.org/wiki/Mass_flow_rate (line 2-3)

Thermo-Nuclear Propulsion

History of Nuclear Propulsion

While nuclear thermal rockets (NTR) were first theorised in the early 20th century, NT propulsion was first tested in 1967 during the United States' NTR development programme that was run from 1955 to 1973. Engineers and scientists had to mitigate multiple chemical and physical issues such as the engine material such that it would not affect other engine components. The programme was only able to achieve ground tests[4]. To this day, there have been no NTRs that have reached orbit or even launched. However, with nuclear energy being proven to be one of the safest forms of energy,[5] more attention is being put onto developing and innovating nuclear technologies. For example, in 2019, US congress approved the equivalent of £140 million in development funding for thermo-nuclear propulsion rockets, so it is likely that this form of propulsion will be seen in testing and eventually in use for deep space expeditions like the upcoming mars missions that should take place by the end of this decade.[6]

How does Thermo-Nuclear Propulsion Work?

During the NTR development programme, as well as subsequent research programmes, have invented various types of nuclear thermal rocket engines which can be separated into different categories depending on their propellant state (i.e solid, liquid and gas propellants). For the ease of writing this report, this report will only cover solid propellant nuclear engines.

While there are different types of thermo-nuclear propulsion engines, the basic components and concepts remain the same: liquid hydrogen is heated to a high temperature in a nuclear reactor which causes the hydrogen to expand through the rocket nozzle to create thrust.

The nuclear reactor is also the same as any basic nuclear reactor but condensed into an engine configuration. Nuclear reactors are able to convert nuclear energy stored within atoms into kinetic and thermal energy. Solid propellant NTRs use Uranium-235 (*Office Of Nuclear Energy*) which is used in a process called nuclear fission. Nuclear fission is when a neutron collides with a uranium-235 atom and splits it into a krypton-92 and barium-141 nucleus and releases 3 more neutrons which go on to collide with other uranium-235 atoms which produce the same outcome and creates a chain reaction.[7]

$$^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \rightarrow ^{92}_{36}\mathrm{Kr} + ^{141}_{56}\mathrm{Ba} + 3^{1}_{0}\mathrm{n}$$

https://chem.libretexts.org/Courses/Univ 1

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4 https://en.wikipedia.org/wiki/Nuclear_thermal_rocket#Principle_of_operation (lines 19-27)

5 https://ourworldindata.org/safest-sources-of-energy#:~:text=The%20key%20insight%20is%20that,solar%20are%20just%20as%20safe. (Chapter 2; lines 37-41)

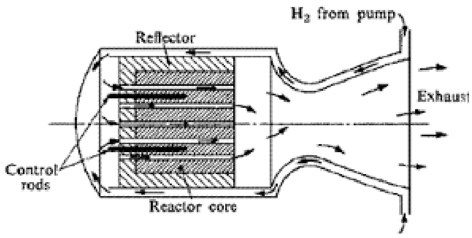
6 *Earth To Marks In 100 Days? The Power of Nuclear Rockets* – Cain, Fraser 2019

7 https://chem.libretexts.org/Courses/University_of_Kentucky/UK%3A_CHE_103_-_Chemistry_for_Allied_Health_(Soult)/Chapters/Chapter_10%3A_Nuclear_and_Chemical_Reactions/10.2%3A_Fission_and_Fusion#:~:text=The%20original%20uranium%2D235%20nucleus,three%20more%20neutrons%20upon%20splitting (lines 1-18)

This can have dangerous effects though as a chain reaction without any form of control system can cause a nuclear meltdown. Engineers and scientists had to try and solve this problem using the constraints that the rocket engine configuration faced which were:

- Small compact space
- Must not be able to affect other engine components
- Must have a control mechanism that is unlikely to fail

Using these constraints and knowledge, scientists and engineers develop this configuration:



http://www2.ee.ic.ac.uk/derek.low08/yr2p 1

As shown in the diagram, it works similarly to a general nuclear fission reactor, but in this case, it is miniaturised. The reactor core contains enriched Uranium-235 which emits radiation, to create a chain reaction the reflector serves the purpose of reflecting neutrons back into the reactor core, increasing the inner temperature of the reactor core. The control mechanism of this engine are the control rods. These rods made of graphite are neutron-inducing, meaning they absorb neutrons.[8] They can be lowered if the nuclear core is creating a chain reaction that is too strong, and can reduce the energy conversion into thermal energy. Meanwhile, as this is happening and is being monitored, liquid hydrogen is being pumped through the reactor core (from left to right). As this liquid hydrogen is passed through the system, it quickly evaporates and expands, causing a large exit velocity, which in turn means a higher thrust.[9]

Nuclear propulsion engines offer multiple benefits compared to chemical rockets which include:

- Higher efficiency – NTR can achieve twice the efficiency of chemical rockets because the propellant is brought to a far higher temperature of around 2500°C. (*X-Energy*)
- Smaller fuel payloads - As NTRs only require the nuclear core and liquid hydrogen to be stored, much less propellant can be used to travel similar distance
- Shortened travel times – Since NTRs have a vastly greater specific impulse compared to chemical rockets, they can produce more thrust and reduce travel times between locations. For example, with an upcoming Mars mission, rather than travel times taking around 7 months[10], an NTR could reduce that time by half.

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8 https://nucleus.iaea.org/sites/graphiteknowledgebase/wiki/Wiki%20Pages/Nuclear%20Properties.aspx#:~:text=The%20typical%20impurities%20occurring%20in,as%20possible%20from%20such%20impurities. (lines 12-14)

9 http://www2.ee.ic.ac.uk/derek.low08/yr2proj/nuclearthermal.htm

10 https://mars.nasa.gov/mars2020/timeline/cruise/#:~:text=The%20trip%20to%20Mars%20will,at%20Jezero%20Crater%20on%20Mars. (line 3)

Environmental Effects by use of Thermo-Nuclear Propulsion

It is well known that nuclear forms of power produce nuclear waste. This can include uranium mill tailings, reactor fuel and various other waste that is used during the process[11]. As such, the use of this nuclear power within rocketry can have large affects on the human health over a large period of time if it is not managed correctly.

As shown within the decay equation above, the nuclear fission of Uranium-235 produces Krypton-92 and Barium-141. These isotopes are unstable and will decay into other particles, which would release additional radiation[12]. To avoid this waste being released into the atmosphere, some form of a magnetic field will have to be present within the engine. This is because Krypton-92 is diamagnetic[13] while Barium-141 is magnetic[14]. Krypton-92 being diamagnetic means that it experiences low forces of magnetism when there is an applied magnetic field. Although it experiences of low forces of magnetism, the fact that only nanoparticles of Krypton-92 are produced means that it will easily be attracted to a magnetic field that is relatively larger. As a result, the waste produced is stored within the engine and the only form of waste being produced is the exhaust which provides the thrust for the rocket, making the process safer.

Additionally, while the waste may be stored, radioactive decay will still occur within the engine, meaning neutrons and electrons will be always emitted from the nuclear core. This can have a large affect on the surrounding people such as technicians, inspectors and any onboard crew. This can increase cancer rates within staff as well as any surrounding fauna and flora in the surrounding region. Other effects may include:

- Contamination of water supplies
- Radioactive dust particulates being blown into high-density residencies
- Damaged internal components

To potentially mitigate this, a thicker outer body panel could be used. However, this would be unfavourable as this would make the rocket engine more inefficient. Instead, the rocket engine could be lined with lead, which has a very high density which is why it is generally used within space vehicles[15]. Alternatively, the same features could be used from current spacecraft which protects astronauts from radiation in space – bumper shields made of thin aluminium sheet with a net of Kevlar and epoxy with air gaps in between to slow down radiation particles[16].

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[11] https://www.eia.gov/energyexplained/nuclear/nuclear-power-and-the-environment.php#:~:text=Nuclear%20energy%20produces%20radioactive%20waste,health%20for%20thousands%20of%20years. lines 15-17

[12] https://www.school-for-champions.com/science/nuclear_reactions.htm#.YzNRp1zMLIU lines 24-25

[13] https://www.priyamstudycentre.com/2020/12/krypton.html (last line)

[14] https://www.sciencedirect.com/science/article/abs/pii/S0921510710005696#:~:text=1.,introduction%20by%20Philips%20%5B1%5D.

[15] https://blog.universalmedicalinc.com/3-different-types-radiation-shielding-materials/#:~:text=Traditional%20Lead%20(Pb)%20Shielding,ray%20and%20gamma%2Dray%20radiation.

[16] https://rsv.org.au/space-radiation/#:~:text=Current%20spacecraft%20have%20multiple%20bumper,to%20slow%20down%20radiation%20particles.

Thermo-Nuclear Versus Chemical Rockets

There are multiple factors that go into deciding whether thermo-nuclear rockets are better than standard chemical rockets. The tables below are used to illustrate clearly the advantages and disadvantages of both:

Thermo-Nuclear Propulsion	
Advantages	**Disadvantages**
Higher efficiency – Isp of 900 sec	Limited research into propulsion method
Compact engine design makes rockets required smaller for the same journey	Complicated design with high risk of failure
Generate considerably more energy compared to chemical	Difficult to mitigate mechanical issues created by radioactive decay

Chemical Propulsion	
Advantages	**Disadvantages**
A lot of research has been done into this propulsion method	Weight of fuel required scales exponentially as a greater velocity is required
Fuel types (oxygen and hydrogen) are in abundant supply	Larger environmental effects from CO2 release
Relatively easy to manufacture engine components	Difficult to store fuel for long durations due to boiling points

As shown above, there are multiple benefits and complications to both thermo-nuclear and chemical propulsion.

However, for longer space expeditions, I believe that thermo-nuclear propulsion is more ideal. This is due to one of chemical propulsion's main drawback – the weight of fuel[17]. To determine whether chemical rockets are available for use in deep space expeditions, the Tsiolkovsky's Rocket equation can be used.

$$\Delta v = v_e \ln \frac{m_0}{m_f} = I_{sp} g_0 \ln \frac{m_0}{m_f},$$

https://en.wikipedia.org/wiki/Tsiolkovsk 1

Where:

- $V_e = I_{sp} g_0$ is the effective exhaust velocity
- m_0 is the initial total mass
- m_f is the final total mass

Rearranging this equation to make the initial total mass the subject we get:

$$m_0 = m_f e^{\Delta v / v_e}$$

https://en.wikipedia.org/wiki/Tsiolkovsk 2

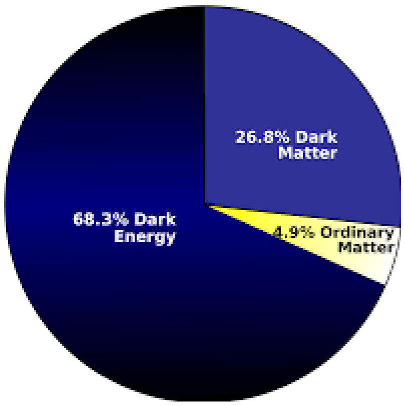
Due to the exponential function, we can see that an initial total mass of propellant grows exponentially with a desired Δv. This makes chemical rockets extremely ineffective when it comes to deep space expeditions where a high Δv is required – making thermos-nuclear propulsion more desirable.

[17] https://blogs.scientificamerican.com/life-unbounded/why-chemical-rockets-and-interstellar-travel-dont-mix/

Dark Matter and Dark Energy

Dark energy makes up around 68% of the universe whereas dark matter makes up around 27%. Dark matter outnumbers visible matter by about 6 to 1. The of the rest of the matter we know exists makes up 5% of the universe. The matter we know exists makes up all stars and galaxies, making the other matter a complete mystery. Dark matter does not interact with the electromagnetic force. **[1]** This means that it does not absorb, emit light or reflect it. This makes it extremely hard to spot and scientists have only been able to interpret the presence of dark matter from the gravitational effect it seems to have on visible matter. Scientists ideas assume that dark matter contains “supersymmetric particles” – which are particles that are companion those in the Standard Model.

The Standard Model is a theory that the universe is made up of a few basic building blocks, called fundamental particles, driven by four fundamental forces. **[2]** These four forces are called the strong force, the weak force, the electromagnetic force, and the gravitational force. Gravity and the electromagnetic force both have infinite ranges, but gravity is many times weaker than the electromagnetic force. However, the weak and strong force are only effective over short ranges and only influence at the level of the subatomic particles.



In 1933, Swiss American astronomer Fritz Zwicky discovered that the mass of all the stars in the Coma cluster of galaxies only provided 1% of the mass needed to keep the galaxies from escaping the gravitational pull of the cluster. **[3]** For decades, the truth behind this missing bulk remained a mystery, until the 70’s when two American astronomers Vera Rubin and W. Kent Ford proved its existence by observing a similar phenomenon: the mass of visible stars in a normal galaxy is only about 10% of the mass required to keep them orbiting the galaxy's centre. “In general, the speed with which stars orbit the centre of their galaxy is independent of their separation from the centre”. **[3]**

There are many theories surrounding dark energy and dark matter, but it still remains a mystery to this day. **[4]** One theory is how space gets energy from the quantum theory of matter. This theory involves when “empty space” is actually full of temporary particles that are constantly being created and disappearing. However, when scientists tried to calculate how much energy this would give the space, the answer came out $x10^{120}$ wrong. This answer was wrong by a lot, so the theory of dark energy remains an enigma. Another explanation for dark energy is that it is a new type of dynamical energy fluid or field that fills all of space but has the opposite effect on the expansion of the universe as matter and normal energy. **[4]** Theorists have called this ‘quintessence’ but if this is the answer, we still do not know what it is, how it interacts with other things, or why it exists. So, the mystery persists. The last possibility is that Einstein’s theory of gravity is incorrect.

Dark matter can also explain some optical illusions that astronomers see in the universe. **[5]** “For example, pictures of galaxies that include strange rings and arcs of light could be explained if the light from even more distant galaxies is being distorted and magnified by massive, invisible clouds of dark matter in the foreground-a phenomenon known as gravitational lensing.”

Scientists at CERN’s Large Hadron Collider are working on generating dark matter particles to study on. Varying ideas say that dark matter consists of exotic particles that don’t interact with normal matter or light, but they still exert a gravitational pull. **[5]**

Dark energy’s discovery in the 1990’s shocked many in the science industry. Before, scientists assumed that the attractive force of gravity slows down the expansion of the universe, but when two independent teams measured this, **[5]** they found it was actually speeding it up. A physicist compared this to throwing a set of keys into the air and instead of them coming straight back down, they just kept on flying upwards. “Scientists now think that the accelerated expansion of the universe is driven by a kind of repulsive force generated by quantum fluctuations in otherwise "empty" space.”

Many scientists have also noted that the known properties of dark energy are compatible with the existence of a cosmological constant, a mathematical Band-Aid that Einstein added to the general relativity to make his own equations fit with the concept of a static universe. **[5]** As stated by himself, dark energy is believed to be a repulsive force that counteracts gravity, this keeps the universe from collapsing.

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