THE WILSON'S INTRIGUE

STEM Issue 9: April 2023

Introduction

The Intrigue Team is back once again to present you with a new issue of the Wilson's Intrigue, filled with incredible articles from writers in Years 12 and 13. Issue 9 will be the final issue produced by the current editorial team and, whilst there were certainly ups and downs, on behalf of the whole team, we would like to say it's been a pleasure.

As always, the magazine is completely independent and student-run; this requires enormous volumes of time from pupils all over the school. Alongside the writers who provide the inspiring articles, the editorial team also work diligently, sacrificing their own time to help format and refine the articles to the highest standard possible. We would also like to show appreciation for staff, namely Mr Lissimore, who selflessly engages and helps the magazine reach new and unimaginable heights. We look forward to seeing what the new editorial team brings to the table to help the Intrigue achieve new heights.

Our Mission

- Expand your knowledge
- Contribute to the Wilson's community
- Make complicated parts of science more accessible
- Popularise science and make it more interesting
- Inspire creativity through wider research

Acknowledgements

This issue would simply not be possible without the perseverance of the writers and editors, skilfully balancing their school and super-curricular explorations. Their intrigue for STEM and enthusiasm to share their research are the fundamental pillars of the magazine. A massive thank you to all students involved for their contributions!

A special thanks must go to Mr Benn, Mr Carew-Robinson, Dr Cooper, Mr Jackson, Mr Lissimore and Miss Roberts for once again proofreading and verifying the accuracy of our articles and the magazine as a whole.

If you would like to write in the tenth issue of the STEM magazine to indulge in researching and sharing a STEM curiosity, please email Tejas and Youyou at *GADKARIT@wilsonsschool.sutton.sch.uk* and *YUY@wilsonsschool.sutton.sch.uk* for more information.

Founded by Devanandh Murugesan and his team of editors in September 2019

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DID YOU KNOW?

The Vessel is a public landmark located in the Hudson Yards neighbourhood of New York City. The Vessel is a 16-story, 150-foot-tall structure made of 154 flights of stairs, 80 landings, and over 2,500 steps. The Vessel is designed by Thomas Heatherwick and was built at a cost of $200 million.

Engineering Section

Front view of the SR-71 Blackbird

The SR-71 Blackbird

By Henoc Lakshman (Y12)

The Lockheed SR-71 "Blackbird" is a long-range, high-altitude, Mach 3+ strategic reconnaissance aircraft developed and manufactured by the American aerospace company Lockheed Corporation [1]. During its incredible service, it served in the US Air Force and was later used by NASA to conduct in-depth research about extreme flight. Cruising at 3.2 Mach (3.2 times the speed of sound), at an altitude of 85,000 feet, the Blackbird broke seemingly impassable records and proved to be the fastest manned, air-breathing aircraft in history. Despite its retirement from service in 1999, its astounding engineering and perplexing design have influenced modern aircraft globally, including fifth generation fighters that are currently in production.

This powerful machine was designed for multiple purposes. Originally, it was used as a reconnaissance aircraft; its main missions would have been to capture images and collect information by spying on regions in the Soviet Union. However, it was also used for experimental purposes. In fact, multiple Blackbirds and their variants were used by NASA to test the most extreme flying conditions. They performed exceptionally due to their frightening speed and altitude. The challenging operating environment in which they flew made the aircraft excellent platforms for conducting research and experiments in a variety of disciplines, including aerodynamics, propulsion, and thermal protection materials [2].

Arguably, the most significant contributor to its success was its speed. Engineers had the challenge of enabling the Blackbird to cruise at Mach 3.2, which was achieved by using two turbo ramjet engines. Before we can understand how a turbo ramjet engine works,

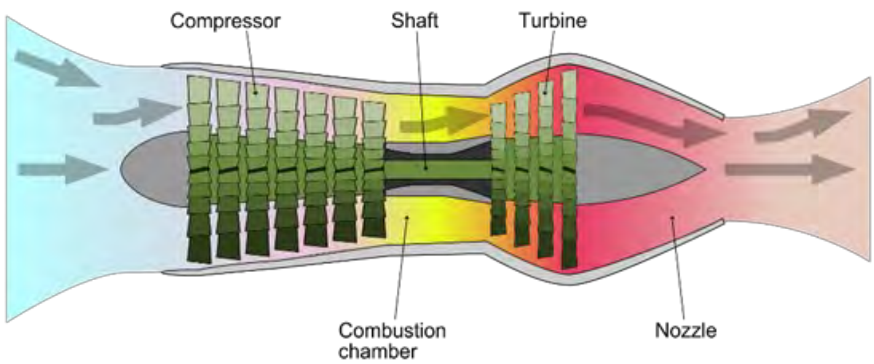


Diagram of the Turbojet Engine

we first need to understand the functioning of a normal turbojet engine.

The diagram below illustrates the turbojet's basic functioning. Air taken in from an opening in the front of the engine is compressed to three to twelve times its original pressure in a compressor [3].

Fuel is added to the air and burned in a combustion chamber to raise the temperature of the fluid mixture to about 1,100°F (593.3 degrees Celsius) to 1,300°F (704.4 degrees Celsius) [4]. This hot air passes through the turbine, which powers the compressor (so more air can be compressed) before passing through to the nozzle, where it accelerates as it expands, generating thrust. The thrust produced is enlarged by the shape of the nozzle because airflow is forced to converge as it leaves the nozzle.

At subsonic speeds, the Blackbird's engines would function as turbojet engines, with air being pressurised by the compressors. However, at supersonic speeds, the engines were adjusted to function as ramjet engines. In a ramjet engine, the cone, which can be seen in the image, is extended out of the engine for supersonic flight. It used to direct airflow through to the afterburner, bypassing the normal combustion engine. An afterburner is an additional combustion engine, which increases thrust for supersonic flight. Due to the afterburner, thrust is increased, enabling the SR-71 to reach high speeds of Mach 3.2. The alteration of airflow which combines the turbojet and the ramjet engines is called a turbo ramjet engine.

Another major engineering challenge faced by the design team was the heating up of the metal bodywork. At Mach 3.2, the SR-71 would heat up to over 260°C, hot enough to soften aluminium bodywork. This is because of the high level of friction experienced between the air particles and the aircraft body at supersonic speeds. Lockheed engineers used titanium for 92% of the aircraft, and in the 1960s, this required inventing entirely new fabrication technologies [5]. Titanium had a melting point of 1668°C so would maintain the aircraft structure, despite the powerful friction. Furthermore, the cockpit windows were made of

heat-resistant glass, to prevent damage from the frictional heat.

As objects get hotter, they expand, so if the bodywork of the Blackbird expanded, parts of the aircraft would loosen, causing damage, making heat-resistance a vital element of the aircraft.

The SR-71's shape was in fact purposefully engineered to reduce the probability that it was detected by RADAR. The curves and non-linear sides of the aircraft deflect radio waves so that detecting the SR-71 using RADAR would be extremely difficult. This increased the stealth of the aircraft and enabled it to carry out its spying missions successfully.

Although many have not heard of the SR-71, its introduction and service have revolutionised the field of aeronautical engineering, with the wealth of data collected by NASA from several experiments having paved the way for innovative new technologies. For example, like the Blackbird, the B2 Spirit bomber was carefully designed with smooth curves and a non-linear fuselage to deflect radio waves and maintain high stealth, making the B2 the most effective bomber in the world. Furthermore, the Blackbird has inspired the creation of much faster aircraft, such as the unmanned X-43, which had a top speed of Mach 9.64.

The legacy of the SR-71 lives on to this day as one of the most legendary aircraft in history.

Edited by Matteo Cascini

Aerodynamics in Sports

By Minhyuk Shin (Y11)

Aerodynamics. A word that is associated mainly with the high-performance racing cars of F1, streamlined cyclists and most other sports, where reducing fluid resistance rewards athletes with a faster time. However, aerodynamics plays an active role in all sports (assuming that you aren't playing in a vacuum!) and influences how equipment used in sports interacts with fluids (any liquid or gas).

One such sports where the importance of aerodynamics is overlooked, particularly from a spectator's viewpoint, is football. Aerodynamics influences how footballs behave whilst in flight, and has guided the development of techniques when striking the ball. Not only this, but football manufacturers have invested into painstaking research to uncover the secrets of fluid mechanics and how they influence the flight of footballs.

Aerodynamics is a major part of ball sports, impacting the reliability of the different balls used as well as influencing technique heavily in sports such as tennis and football where different striking patterns cause variations in spin. Sticking with football, kicking a football off centre - e.g. bottom left with your right foot causes the ball to rotate in an anticlockwise direction. This creates a pressure difference between the right and the left side of the ball because there is greater friction on the right side (as a result of airflow closer to the ball). The higher pressure on the right side of the ball explains the Magnus effect as following:

$$P = \frac{F}{A}$$

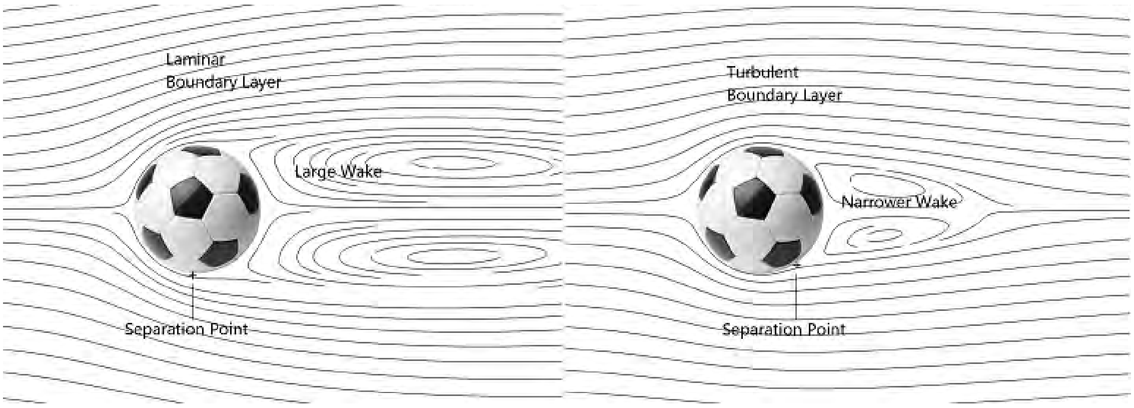
If the pressure increases and A is constant, the force F must increase as well.

The increase in the force in the direction perpendicular to the initial trajectory means that the ball curves in the direction of this force away from its initial path. An anti-clockwise rotation would result in an increase in the force acting left whilst a clockwise rotation would cause an increase in the force acting right. This creates the Magnus effect, which is responsible for the ball curving and can be applied to other types of spin such as topspin and backspin as well as side spin.

This can be observed in other sports such as tennis, where topspin generated by racket movement is created by a vertical clockwise rotation following contact. Here, the Magnus effect acts downwards and goes to further show how widely aerodynamics can impact ball sports.

Going back to football, the design of the ball can impact how stable it is during flight and can drastically impact the playing experience. An infamous example of an ill-designed football is the "Jabulani" from the 2010 South Africa world cup. Many players complained about the unpredictability of the ball during flight and various aerodynamics tests that preceded the tournament revealed the responsibility of a large, turbulent wake and a laminar boundary layer for the "knuckling" effect.

The Jabulani had a few major design flaws that impacted the consistency of its velocity and the size of the wake including the lack of grooves or features such as small dimples to create a turbulent boundary layer on the ball meant the airflow was further from the football, creating a large wake behind the ball (at lower velocities).



A boundary layer in a moving ball is a thin layer of the fluid it is travelling through (typically going to be air) that lies very close to the surface of a body in motion. Pressure in this region causes the airflow to separate around the ball with the velocity of the air molecules increasing as the distance from the ball increases.

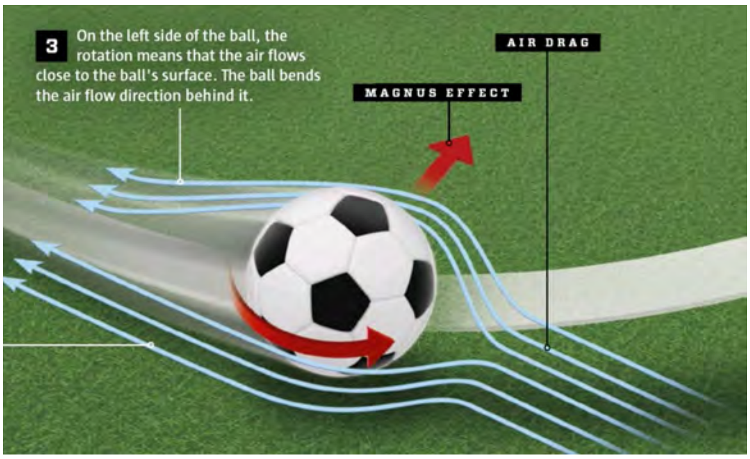
The laminar flow region had high drag coefficients, while at higher speeds the ball decreased its drag coefficients by creating a smaller wake. This created a significant velocity range, which was responsible for some of the unpredictability.

Furthermore, the grooves that were present on the ball were ineffective in creating a more consistently turbulent boundary layer, and meant any wind would catch these grooves and cause further movement.

Other sports avoid similar effects, such as golf, which uses dimpled golf balls. The dimples on the surface of the golf ball create a turbulent boundary layer, allowing airflow to be closer to the ball [3]. This means a smaller wake is formed, decreasing the area of low pressure behind the ball resulting in a lower drag coefficient. This creates a more stable, predictable flight that will last for a longer time period due to the reduced air resistance (dimpled golf balls travel two times farther than old non dimpled golf balls). Modern footballs now take a similar approach, with the new "Al Rihla" ball for the 2022 Qatar world cup having a textured surface and small patterns of dimples to help improve its aerodynamic performance.

As our understanding of aerodynamics developed, we have seen a significant increase in research to create more aerodynamically sound sporting equipment. This has improved the experience of the public from a spectator's viewpoint and despite several controversies, aerodynamics is undoubtedly embedded in sporting success.

Edited by Matteo Cascini



The Fastest Man Alive

By Sasank Bavaluru (Y11)

Have you heard of the Columbia Space Shuttle? What about the Gemini missions or The Apollo Rocket? What about Neil Armstrong or Buzz Aldrin – the first people to set foot on the moon? Whether you're an aerospace enthusiast or not, these names would definitely not be new.

Engineers at NASA are always tasked with the extremely difficult aim of developing systems that are suitable during re-entry into the atmosphere. Due to an extremely high proportion of collisions with air particles at high velocities, external heating is a problem that spacecraft face during the final stages of the mission. To combat this, materials used to design their surfaces must be able to withstand the high pressures and temperatures that are experienced. But how are they determined? Given that the Apollo missions to the moon took place in 1969, how did engineers at NASA, in an era where there was limited knowledge of hypersonic engineering, decide on what materials would be used to develop these spacecrafts?

During the space race between the USSR and the US in the Cold War, America had a lot to catch up on to match their Soviet counterparts. The X-15 is to be credited greatly [1]. First flown by pilot Scott Crossfield in September 1959 from Edwards Air Force Base CA, it achieved extraordinary capabilities ranging from crossing the Karman Line of the Earth's atmosphere to breaking into the hypersonic regime – Mach 5 above [2][3]. But what any aspiring engineer would pick up, is that behind such awesome capabilities, lie extra-awesome engineers – and that's what had always intrigued me about the plane.

While a typical jet engine wouldn't work at altitudes as high as 350,000 feet (the approximate maximum height reached by the plane) due to the thin air, rocket-based propulsion was necessary [4]. The fuel of the X-15 was completely unorthodox – while normal spacecraft hoping to break into such extreme regimes of flight would typically use a hydrocarbon-based propellant, engineers at National Advisory Committee for Aeronautics (NACA) settled upon the idea of liquid ammonia mixed with a liquid oxygen oxidiser to create a monopropellant fuel [5]. Ammonia was considered best due to its specific impulse – the amount of thrust produced per unit fuel mass. To reach the hypersonic regime, engineers calculated the aircraft required 240kN of thrust, and ammonia would produce enough of this, burning for just over two minutes. Kerosene-oxygen was also a big contender for the fuel but was dismissed due to its bad habit of forming impurities and clumps that could clog smaller pipes.

The plane could use traditional aerodynamic control surfaces within the earth's atmosphere (such as ailerons), which would prove useless in space due to the absence of air. To overcome this issue, hydrogen peroxide was used in thrusters to control the attitude of the plane due to its low mass. To save fuel, the plane would be flown up to 40,000ft hanging off of a pylon from the B52 for fuel to be burnt [6].

The shape of the plane was also a big concerning factor during its re-entry. As no knowledge of dynamics in space were known, all traditional ideas had to be left at the door, including those from the holy "Principia Mathematica" written by Newton. The plane was developed with a mix of a pointed and blunt nose in order for a shockwave to be formed during the re-entry [7]. This completely shielded the wedgetail from the high pressure air but exposed the lower part of it to the aerodynamic friction of the denser air. This made the lower part a crucial element in steering but due to increased drag forming as a by-product, it would be ditched with a parachute in the late stages of the flight.

Speaking of heating, the materials scientists developing the airframe had to consider the 649 degrees Celsius experienced due to aerodynamic heating at high-Mach flight, or even on the way to reaching this while still being in the atmosphere. To do this, a material that would have a high melting point and be strong enough to withstand the high pressure from air would have to be developed. This immediately ruled out any form of pure metallic substances. Scientists, did the only smart decision any scientist would do to make a strong airframe – they alloyed. After rigorous testing, the best alloy for the plane was deemed to be an Iron, Niobium, Nickel and Chromium alloy known as Inconel-X [10]. This legendary alloy was perfect for withstanding the high temperatures and could take on the extreme pressures of the hypersonic regime, but it came with drawbacks of its own. Firstly, as a result of the high temperatures, the Inconel inevitably underwent thermal expansion, causing an external pane to explode

The X15 Aircraft over the California Mojave Desert

during a test-run. To combat this, engineers developed gaps in the leading edge of the aerofoil for the Inconel to expand into and replaced the framing metals of the cockpit window with Titanium to prevent shattering. This was principally also due to the fact that the aircraft underwent extreme differences in local heating, and this could be extremely dangerous during high speed flights. An ablative material was sprayed onto the Inconel-X and would essentially wear away and act as a galvaniser for sacrificial potential.

On the fateful day, 3rd October 1967, the aircraft, piloted by William J. Knight, flew its 188th cycle and completed the task of breaking into the hypersonic regime – at 6.7 Mach . However, the ablative material galvaniser was completely destroyed due to leakage from the liquid oxidiser tank followed by parts of it burning away – a bad habit not known in advance [7]. While the X-15 did not make it to the double century, it was without a doubt one of the most influential aircraft to be made, laying the foundations for the Gemini and Columbia missions. So next time you look up at the moon and wonder how Armstrong got there, think about the X-15 and the insane beauty of its engineering. To this day, Knight sets the record for being the fastest man alive.

Edited by Matteo Cascini

Differentials

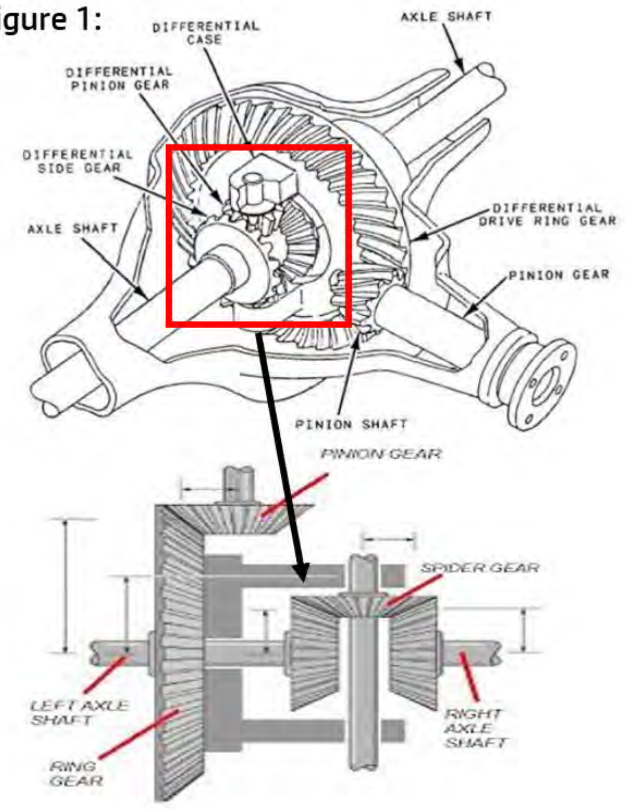
By Akshay Gopee (Y11)

Turning, even upon icy or unpaved roads, is made to seem simple, yet people do not appreciate the gear-train that permits vehicles to effortlessly drive around curves. From your everyday car journey to the phenomenon behind drifting, vehicles must both be able to turn and do so efficiently. So, what allows them to do this? The answer: differentials.

You may have heard of differentials in Mathematics, equations including the derivatives of functions, but the small gear alliance, which shares its name, has been far more revolutionary in engineering. When turning, the inner and outer rear wheels must travel at different speeds, due to the different distance that must be travelled around the bend at the same time [1]. Wheels connected on the same axis cause them to receive the same power from the drive shaft, and so travel at an equivalent speed. This causes stuttering: the outer wheel, at the same speed, will take longer to travel a larger distance. Hence, the outer wheel cannot drive fully and drags instead. This is inefficient in terms of both energy consumption and time.

But how does a differential help? Its main function is to allow the drive wheels to turn at different RPMs [2]. In a two-wheel drive vehicle, with an open differential, a pinion gear is attached to the drive shaft (see Fig. 1). The pinion gear has a larger ring gear locked in, where the ring gear has a spider gear rotating upon its axis. The spider gear turns with the ring gear yet can also turn independently. Meshed to the spider gear, are two side gears, each controlling a drive wheel. When travelling in a straight line, the spider gear rotates upon the axis of the ring gear, causing the RPM to be

Figure 1:



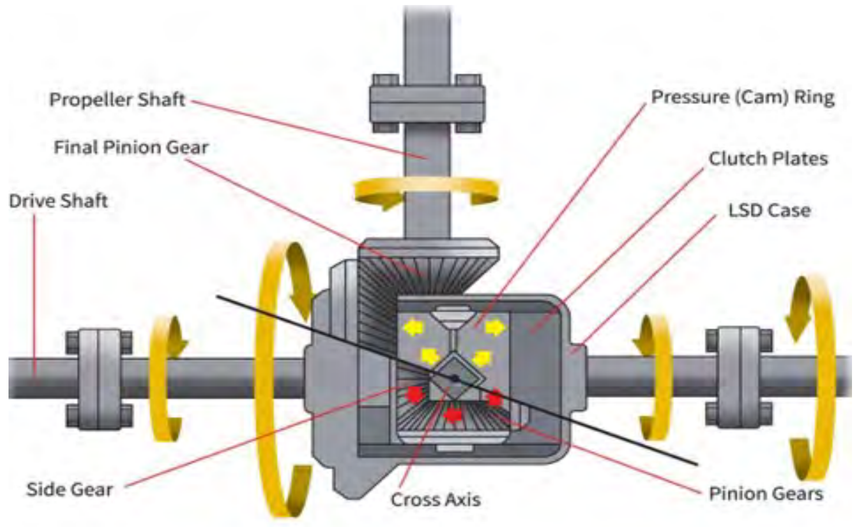
constant. However, the differential excels during turning. For example, when turning left, the right wheel must travel a larger distance. Whilst also rotating upon the ring gear's axis, the spider gear must also rotate upon its own axis. Through this rotation, the spider gear causes the side gears to rotate at different speeds. In this case, the right-side gear must rotate quicker than the left to make the right outer wheel travel faster.

Furthermore, not only is the differential responsible for turning, but it also conducts the balance of acceleration and top speed. The pinion gear has less teeth compared to the ring gear, meaning it travels faster comparatively:

Teeth of Ring Gear/Teeth of Pinion Gear = Speed of Pinion Gear/Speed of Ring Gear

This is known as the axle ratio [3]. This directly affects the acceleration and top speed. A high axle ratio (4:1) causes better acceleration but slower top speeds. A lower ratio (3:1) causes lower acceleration but faster top speeds.

However, though open differentials are



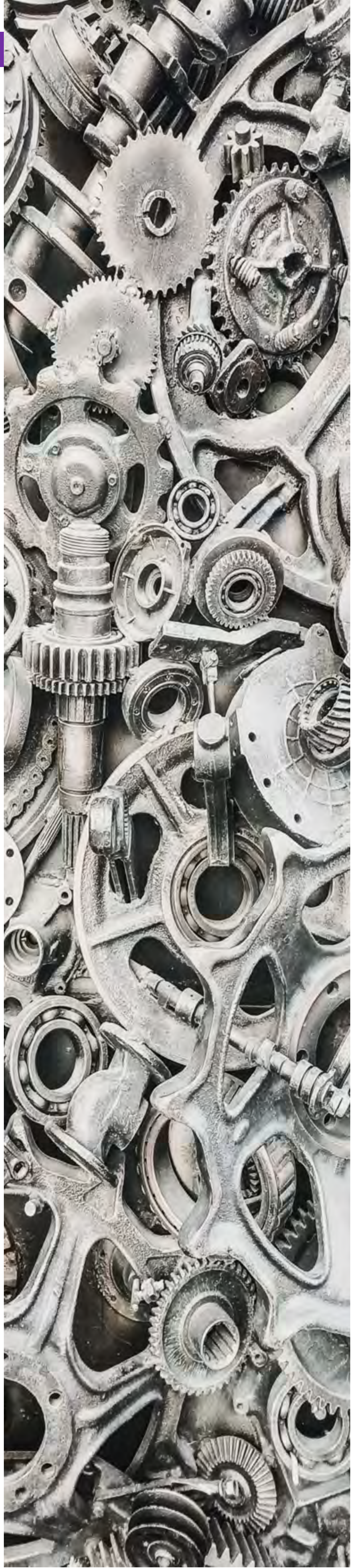
cheaper, they come with a large inefficiency – the inability to cope with traction variation. Areas of low traction, such as ice, will divert power from the engine to that wheel, causing slipping.

In 1932, Ferdinand Porsche created the first Limited Slip Differential (LSD), designed to resolve the issue with traction. The LSD limits the independence of the two axles and thus limits power directed towards the wheel with the least traction [4]. To maintain movement, the wheel with the most traction receives the most power, avoiding the inevitability of slipping with an open differential. The main type of LSD is a clutch-based system. They involve two spider gears, sitting between pair of pressure rings. These are fitted to an outer casing and the side gears are fitted into the rings. Clutch pack makes up friction discs and steel plates either side of pressure rings. The clutch pack tightens together, and frictional forces makes it move as a solid unit. If one wheel loses traction, the engine power would meet with the resistive clutch pack, diverting the energy away from the wheel with least traction, to the other wheel.

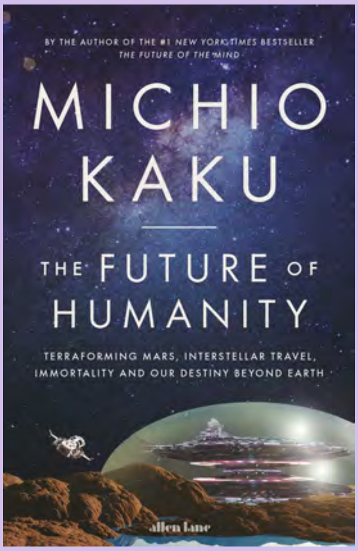
For everyday driving, LSDs are key. However, a more unique differential is used in drifting. The spider gears are welded together so that they can rotate at the same speed. The welding is significant because it minimises the power loss from the drive shaft, ensuring both wheels always get power. This makes oversteering easier, creating the mesmerising puffs of smoke due to friction.

The propensity to change direction efficiently has been revolutionary for modern design of vehicles, by not only being significant in everyday use, but also as a source of awe in the creativity of the first Porsche and drifting. It leaves us to consider the true impact it has had in modern engineering through its simplicity and transferability.

Edited by Matteo Cascini



"THE FUTURE OF HUMANITY" by Michio Kaku



The book I read was called 'The Future of Humanity', written by Michio Kaku. I am passionate about aerospace and aviation, and this book was perfect for me. It rekindled and increased my love for these topics and hooked my in the second started reading it. Kaku intricately explains the history of rocketry, space exploration and robotics, and how humans can go from living on the Earth to colonising planet after planet, becoming an inter-planetary species. Without complicated mathematics and complex physics, Kaku analyses NASA's plans to terraform Mars, and the technology required to do it. He aims to take the reader on a journey of space travel, from the few who laid the foundations and planned the prototypes of the gargantuan rockets, to the successful technological advances that have made the science-fiction dreams of colonising Mars a reality.

The book starts by describing the rich history of rocketry and how influential scientists laid the foundations of space exploration. One major contribution was the use of liquid rocket fuel as opposed to gas fuel. It later progresses to discuss the development of rockets, from the Saturn V rocket which took the first astronauts to the moon, to the Falcon Rocket and the Space Launch System rocket, developed by the private companies SpaceX and Boeing (alongside NASA). Kaku describes how humans can become an inter-planetary species by exploring the planets and moons in our solar system which have the potential to sustain human life. He discusses Saturn and Jupiter and their extreme climates. Kaku clearly explains how the progression of artificial intelligence and autonomous robots can make space travel more efficient. There are, as he calls them, waves of technology, in which technological advances are made in quick succession. The first wave was the foundation of the theories of mechanics and thermodynamics, followed by the second wave involving electricity and magnetism. The third wave is still in progress and involved computing, modern telecommunications and the internet. Most importantly, the fourth wave is the age of artificial intelligence, nanotechnology and biotechnology, which will allow humanity to become interplanetary.

In my opinion, Kaku achieves what he set out to do. I was taken on a fascinating journey. I loved every second of the book. He passionately describes the journey to Mars using a detailed plan of action. He explains how humans can not only reach Mars with the behemoth Space Launch System rocket required, but how they can grow crops through genetic engineering, and how they can process the abundant iron oxide and create important metals for infrastructure.

My favourite part of the book was the chapter called Gas Giants, Comets and Beyond; Kaku describes the multiple space probes that humans used to learn more about the solar system. The Cassini space probe, which orbited Jupiter for thirteen years, ended its mission in September 2017 by plunging into Saturn's immensely powerful atmosphere. However, it conducted research of Titan, one of Saturn's moons. Titan, the second largest moon in the solar system, boasts extreme climates, with a core of liquid (and partially solid) hydrogen. This chapter developed my love for aerospace and described these alien landscapes, painting fascinating scenes in my mind. Kaku also describes the most similar planets, Earth, Mars and Venus, and how they started off as habitable but had different fates that changed them forever.

By Henoc Lakshman (Y12)

DID YOU KNOW?

Fibre optic cables are thinner than a strand of hair sometimes only five microns in diameter! The light doesn't actually travel faster than electrical current but fibre has an increased capacity, meaning it can send more at once, making it more efficient.

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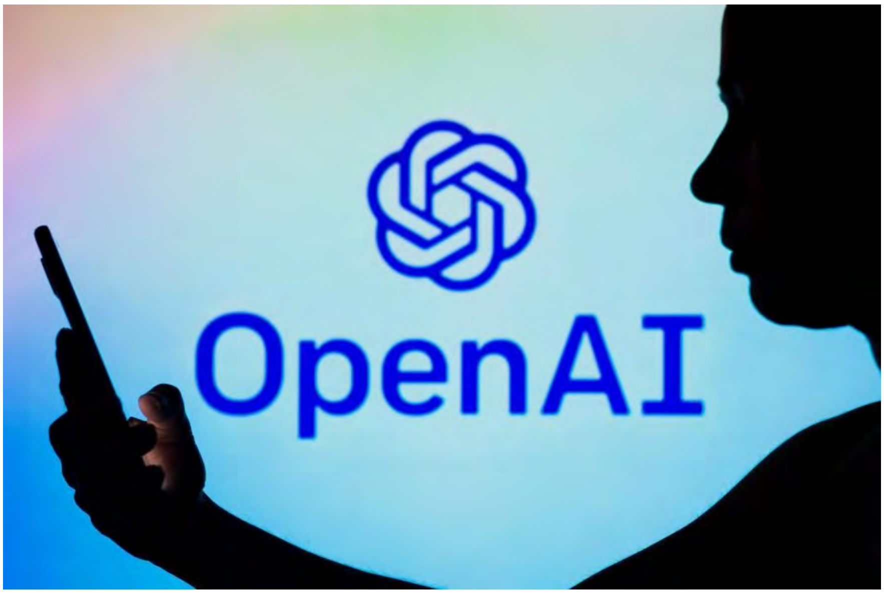
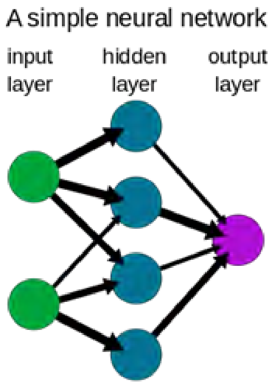


Okay Google, write me an article for the Wilson's Intrigue

How did GPT-3 achieve its generational leap in Natural Language Processing (NLP)

By Jesse Luo (Y12)

Founded in the heart of San Francisco in 2015, OpenAI is a start-up dedicated to AI research and deployment that aims to "ensure that artificial general intelligence benefits all of humanity" [1]. The latest iteration of its Generative Pre-Trained Transformer (GPT-3) model, released in 2020, is undeniably the best and most reliable natural language processing neural network to date. Content generated by the "largest neural network ever created" were so indistinguishable from human-made content that only 52% of judges reading articles written by GPT-3 correctly identified them as machine-made.[2]



Neural Networks [3] (NNs) and Recurrent Neural Networks (RNNs)

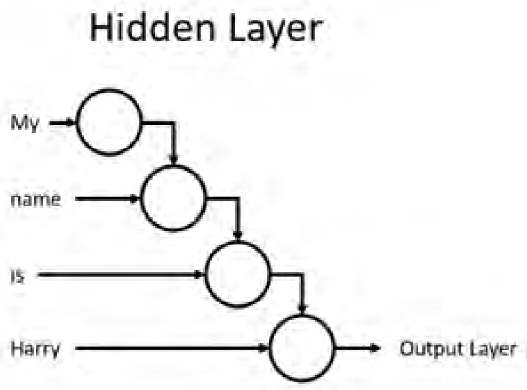
To understand how GPT-3 achieves such astonishing results, we must first understand the basic technique that most mainstream artificial intelligence systems over the past 10 years have used - neural networks.

As the name suggests, neural networks borrow their inner workings from the human brain. Information is passed through the human brain via electrical signals between individual neuron cells which neural networks mimic by sending information from the input layer to the output layer through hidden layers, which are all comprised of many nodes that are interconnected with each other. In general, neural networks are also feed-forward [4], which means that data is only allowed to flow in one direction.

In the input layer, one type of data is supplied to each node. In the hidden layer, nodes receive one piece of data from each previous node, multiply the data from each connection by a weight, add all the numbers together. The data only passed forward if the total surpasses a certain threshold. A neural network may also combine multiple hidden layers. Finally, the output of the output layer can be used. Weights are initially random, but as the neural network is trained on (given) more and more data, the weights adjust to provide more accurate predictions. For example, a neural network trained on a dataset of stock market information may be able to output the predicted share price of a specific share. Not very useful when you need to output hundreds of characters to form a sentence instead of one number!

The structure of basic neural networks means that they are only applicable to a limited range of problems, mainly classification problems where a wide range of data is inputted, and a simple number or Boolean expression is outputted. Based on the work of

David Rumelhart in 1986[5], the idea of a Recurrent Neural Network has been popularised over the past 10 years. The fundamental difference with RNNs is that they are not strictly feed-forward. This means that they are much better suited to inputting and outputting long, sequential data like text [6]. Nodes inside the hidden layer of RNNs can output data as input back into other nodes in the same layer or previous layers, which means that the final output of the network combines calculations of every word fed into the RNN sequentially into one piece of data which can then be easily analysed.



The success of the RNN was however short-lived due to numerous factors. The structure of RNNs means that information from earlier nodes is likely to be 'forgotten' by the network (in the example above, "Harry" will make up 50% of the final output whereas "My" will only make up 12.5%), meaning that RNNs struggle to produce paragraphs of coherent text.[7] Additionally, because each node relies on the previous node, RNNs cannot benefit from parallel processing, which makes them inefficient at a large scale.

Transformers – the breakthrough

In 2017, researchers from Google and the University of Toronto released a paper titled "Attention Is All You Need" [8], introducing the Transformer model to the world. This model aimed to improve on previous neural network architectures used for NLP problems by relying "entirely on an attention mechanism" which would allow for "significantly more parallelization". Transformers are the latest, state-of-the-art model in NLP, marking a significant improvement in performance when compared to RNNs [9] and is the model used for every iteration of GPT. In essence, Transformers deliver an improvement by:

1. Using an attention mechanism. Attention is a technique which aims to mimic the way attention works biologically [10], looking at every token (word) inputted and selectively enhancing /diminishing parts of the input data. For example, a model translating the sentence "I don't have my homework because the dog ate it" may highlight links between "homework" and "ate" and diminish the effects of other words. Transformers further builds on this idea by having multi-head attention, meaning there are multiple independent attention mechanisms, allowing for parallelization, as well as self-attention, which just means that a transformer learns how to apply attention by itself.

2. Using positional encoding [11], which means that each word in the data is indexed before being fed into the neural network. Information about word order is stored within the data, unlike in RNNs, which stores this in the structure of the network.

3. The significant improvement in parallelization means that it is simply easier and faster to train Transformers on a much larger dataset, which will inevitable improve accuracy.

Now that we understand transformers, we can finally begin to understand what GPT is. GPT generates data [12], is pre-trained in an unsupervised manner, and uses the transformer architecture. GPT-3 was announced in the paper "Language Models are Few-Shot Learners" in 2020. As the title suggests, when compared with GPT-1 and GPT-2, GPT-3 shows significantly better performance in a zero/one/few-shot setting [13].

GPT-3 was trained on a dataset containing 175 billion parameters, amounting to 800Gb of data. When GPT-3 was

	Definition	Example prompt
Zero-shot	The model predicts the answer by referring to only a natural language prompt	Translate from English to German Cheese:
One-shot	In addition, the model is given one example	Translate from English to German Cheese: Käse Bread:
Few-shot	In addition, the model is given a few examples.	Translate from English to German Cheese: Käse Bread: Brot Water: Wasser Tomato:

tested on CoQA, a dataset designed to test reading comprehension, it achieved an accuracy of 85%, a mere 3% away from the accuracy of a human. [13] GPT-3 has learned to write articles, poetry, stories, and questionable pick-up lines, to translate, to hold pretend conversations, to simplify legal jargon [14], to code, to do maths, but also to write fake news, to mislead people, to be racist, sexist, and discriminatory [15].

parts of the Internet.

OpenAI, the research company that wanted to ensure "artificial general intelligence benefits all of humanity" became a for-profit company in 2019. GPT-3 is now up for bidding [16].

Conclusion

In their original paper, researchers acknowledged the shortcomings of GPT-3. Upon investigation they found that 83% of jobs were likely to be associated with male identifiers. When asked to describe men/women, GPT-3 gave words like 'large' and 'lazy' for men, and 'petite' and 'naughty' for women. GPT-3 was also likely to describe Atheism as 'cool' and 'correct' and described Hinduism with 'Africa' and Judaism with 'Racists'.[13] The very same 'attention mechanism' and raw, unfiltered data that shocked users when experimenting with GPT-3 also meant it was exposed to the darkest parts of the internet.

Edited by Jonathan Peter-Rajan

The following extract has only been edited to fix punctuation where necessary. To generate this, I used OpenAI Playground, selecting the Da-Vinci variant of GPT-3 (the most powerful variant trained on the most data), and used a Frequency penalty and Presence penalty of 1.5, which should discourage the model from repeating phrases verbatim.

Prompt: Write roughly 500 words for an article for a school magazine, explaining what GPT-3 is, how GPT-3 works and the ethical implications of using text-completion models with such high accuracy.

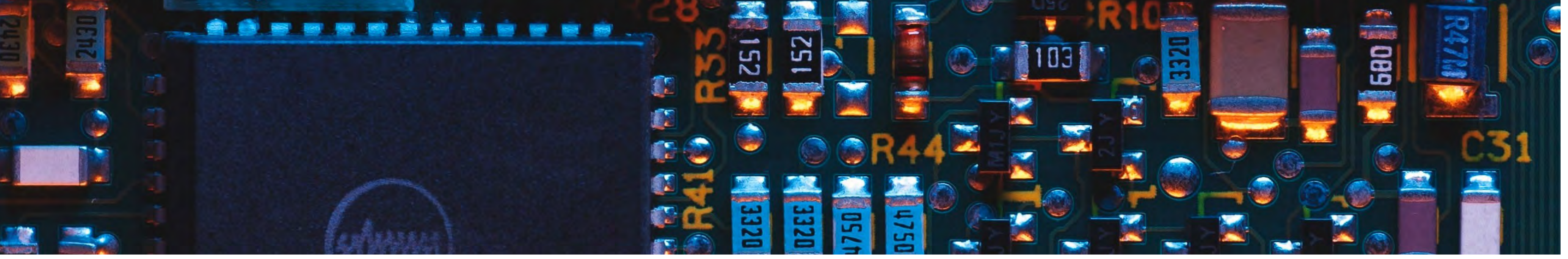
In May 2017, Google released the paper "Natural language processing (almost) from scratch" (GPT-3), which proposed a model for end-to-end natural language understanding. The paper has been widely recognized as a breakthrough in the field of NLP, and GPT-3 has become one of the most popular models for text completion and other tasks.

GPT-3 is a neural network that uses an attention mechanism to read a sequence of words and predict the next word in the sequence. The model is trained on large amounts of data, such as books, articles and websites. When presented with a new piece of text, GPT-3 can generate accurate predictions about what comes next.

The accuracy of GPT-3 has led to concerns about its potential misuse. For example, it could be used to generate fake news articles or spam emails. It could also be used to impersonate someone online, or to create convincing but false reviews about products or services.

There are also ethical concerns about using GPT-3 for commercial purposes. For example, if businesses use GPT-3 to generate customer service responses automatically, they may save money but this could lead to job losses. In addition, there are worries that personal data collected by companies could be used to train predictive models like GPT-3, which would have profound implications for privacy.

As GPT-3 becomes more widely available, it's important to consider both its potential benefits and risks. With proper safeguards in place, GPT-3 can be harnessed for good; without them, it could do great harm.[17]



Quantum Computing

Madhav Chippada (Y12)

Nowadays, everyone has a computer within their hands in the form of smartphones, desktops and even smart fridges. Yet it is easy to forget that just a hundred years ago computers were the size of entire rooms but were only capable of relatively simple things, compared to today. Over the decades, computers have gotten smaller and smaller in size but also more and more power to the point that a 1TB SD card is smaller than a thumb. Can this keep going on forever? Our computer parts and microchips are now reaching the size of the atom and quantum physics may not allow for them to get smaller meaning there is a limit to digital computers.

This problem arises as a result of transistors. Simply put, they are simple switches either allowing information through or not depending on their input. They can be combined in different ways to make logic gates and give outputs only if certain conditional inputs are received. Combining these gates gives you the ability to do basic operations; enough gates can allow you to compute complex problems. Transistors currently sit at around 14 nanometres, smaller than the size of bacteria and viruses. At this scale, quantum physics starts interfering as electrons have a slight chance to just pass through such small objects in a process called quantum tunnelling. This means that they could potentially pass through a blocked transistor leading to many problems as computers would be unable to function.

However, quantum physics both causes the problem and provides a solution. Quantum computers. Instead of traditional bits of information, quantum computers could use qubits. They can be made from ions, photons or electrons and uses their properties, such as the up or down spin of an electron to determine whether it is a 1 or a 0. The advantage of a qubit compared to a traditional bit is that whilst bits are either a 1 or a 0, qubits can be both at the same time. These qubits will remain in what is called superposition where it is in both states and will collapse into one of these states when observed. This is based on the idea of Schrodinger's Cat where a cat is in a box with a container of poison that you don't know if has been broken or not. Until you check on the cat by opening the box the cat can be described as both dead and alive. Similarly, a qubit has a probability of either being a 1 or a 0 and you cannot predict which it will be till you measure it. To demonstrate what this could mean, four traditional bits could have 16 combinations of outputs but can only store one of them at once, whereas four qubits in superposition could store all combinations at once. In fact, 20 qubits could store 1 million values simultaneously.

Another advantage of qubits comes from the concept of quantum entanglement. This is the idea that qubits interact in a way where they are connected. This means that finding the state of one qubit will also tell you the state of the entangled qubit. Qubits can then be manipulated or forced into states using quantum gates that take an input of superposition, entangles the qubits, manipulate probabilities and produce an output of superposition. The outcome would then be measured by collapsing the superposition values into 1s and 0s.

This would allow us to do things we could never do before with traditional computers such as making accurate models of proteins or simulating artificial intelligence on a level never seen before. However, quantum computers do have a few drawbacks: they likely would not be needed in our everyday lives. The massive amount of computing power it provides is not needed for regular use and would likely only be useful for supercomputers and computationally challenging research. Additionally, they would likely be incredibly expensive as it requires many years of research to develop and maintain it. A more dangerous effect of quantum computing is that it could destroy many encryption systems that protect personal and classified information. A traditional computer would take many years to break encryption to find your password, but a quantum computer would be able to do it within hours. This means that information like passwords and bank details would become much more vulnerable to attack by malicious hackers. However, there is hope as post-quantum cryptography is being developed in a way that is designed to be able to withstand quantum computers being used in this way. The future of quantum computing certainly looks bright!

Edited by Jonathan Peter-Rajan

Why do we need many programming languages?

By Boris Hall (Y12) and Nelson Gong (Y12)

Software engineering is becoming a more and more sought-after skill as humanity progresses. There were more than 26.8 million active software developers worldwide by the end of 2021, and this number is only expected to double in the next decade up to a huge 45 million by 2030 [1].

There are thousands of programming languages officially listed on Wikipedia[2]. The three most used languages according to the PYPL worldwide index are Python, Java and JavaScript with the top five languages being used by more than 70% of the world's developers[3]. So this begs the question: why do we need more than these five languages? Furthermore, why do we need more than a single programming language?
Alan Turing, often praised as the father of modern computer science[4] devised the Turing machine in 1936. A Turing machine is a simple abstract machine that is capable of implementing the algorithmic logic of any computer program that is desired[5]: it can add two numbers; it can find the shortest path between two places; it can encrypt data; and the list goes on endlessly.

But these machines go further than being abstract: they have been implemented in real life too. In fact, virtually all programming languages can be described as turing-complete[6]. Turing-completeness is the idea that a program can be used to simulate a Turing machine: that is, it is also capable of implementing any computer algorithm that is desired. Overall, this should mean that every single language has the same constraints as any other language.

Or do they? What kind of "constraints" are we talking about here? As has just been discussed, every language can perform the same algorithms. We have determined that no language has a different constraint of capability over another - but there are other constraints to consider; namely time, purpose and usability.

It is easy to compare how fast two languages execute a given algorithm. However, as it turns out, just because one language is faster at e.g. sorting a list of numbers into ascending order, this does not necessarily mean it is faster at everything. Some languages may be preferable to use over other languages simply based on the time that they execute the desired algorithm in, so this partly answers the question that was put forward.

But this same question arises again - why? Why are some languages slower than others? This brings us to the next two constraints: purpose and usability.

Let us consider an analogy involving wheels. Every size and design of a wheel can perform the same function - turning to make a locomotive force. Why shouldn't we just invent one size and design of wheel and use that for every train, every car, every bicycle? Well, the answer is that we need different variations of wheels to support the weight and the environment on which they are being used. In the same way, multiple turing-complete programming languages are created so that they can be used for a variety of purposes: JavaScript can be used for full stack development; Python can be used for mathematical analysis and artificial intelligence; languages such as C# can be used in game development[7]. Different languages are provided with constraints of purpose in order to maximise their efficiency at performing their task.

One way of categorising programming languages is into higher and lower level languages. In contrast to what their names imply, lower level languages tend to look more like binary or assembly code, the language of the computer, and so seem more complicated and confusing to a human, whereas higher level languages tend to look more like regular human speech[8]. The differences are strikingly obvious to anyone regardless of their level of coding experience. Higher level languages are a lot easier to work with and debug to a human and so can be described as being more usable. Given the opportunity to learn C or Python, lots would choose the higher-level language Python as it is simply a lot easier to learn and grasp the fundamentals of. Quite intuitively, though, Python would be a lot slower than C given any task as this human-like language must first be decoded into the machine-like language for the computer to be able to understand and execute. Let alone the fact that this process takes time, this process is also naturally imperfect and so generates more inefficiencies in the execution of the code[9].

In conclusion, we need more than one programming language in order to perform various different types of computations and without spending years writing out zeros and ones in order to do so in a suitable period of time. After all, it's (more often than not!) worth sacrificing a couple milliseconds of runtime to save many tiresome hours of labour.

AI is beginning to move away from theories and more towards modern day, consumer-oriented applications, which provide immediate benefit to businesses. While we may never see the presence of a fully digitized thinking being, the impacts of AI will continue to grow in the future, improving the customer experience, and providing new opportunities to businesses around the world.

Edited by Jonathan Peter-Rajan

What are Virtual Machines and how do they work?

By Joseph Oduyemi (Y12)

In the past, if you had a Windows operating system (OS) and you wanted a Mac OS, you would have needed to purchase additional hardware — i.e., another desktop computer or laptop — with the relevant OS. Furthermore, despite there being methods to boot from different operating systems on a device, and one can be used at a time, which is much less effective than being able to do both. Thus, perhaps the most common way to use two different operating systems at once is through virtualisation.

So, how does it work? The default OS and complete system hardware is called the host. Upon this, there is a " virtualisation layer" which facilitates a file that program that emulates a physical computer known as a virtual machine – with this a different OS can be run simultaneously with the host OS. However, the application and hardware usage of this virtual machine is controlled by the host.

The key component of virtualisation is something called a hypervisor, or virtual machine manager (VMM). If we imagine a computer with its host OS as Windows, the hypervisor runs on the conventional host OS, with the hardware being partitioned such that a proportion of the physical resources — for example the RAM, CPU and storage — can be used by one or more virtual machines as a virtual CPU, RAM, and so on. One of great things about this is that users can have total control over how much RAM they allocate so that they can speed things up within the constraints of the hardware.

One of the key concepts of virtualisation is that of isolation — the virtual machine thinks that it is an independent computer, believing it has access to all the resources, even though its access is controlled by the hypervisor. Therefore, it doesn't try to 'compete' for resources.

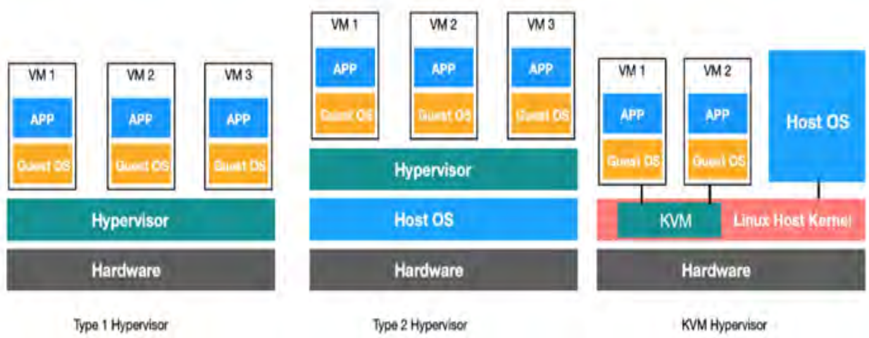
The Problem with IoT

IoT heavily revolves around monitors constantly collecting data in order to do their task to the best of their ability. For example, smart lights that turn on when you are in a room monitor your presence so the device knows where you are in the house or if you're not in the house at all! This is problematic if the data falls into the wrong hands. If a burglar gets hold of this information they can very easily rob your house knowing exactly when you are not at home. Furthermore, hackers can hack into devices that use IoT and will be able to extract the wifi password and even hack into other devices connected to that wifi such as a mobile phone or laptop and the data could be breached. This is why tech businesses should prioritise privacy whilst developing their products, keeping data encrypted so it is not vulnerable to hackers.

Type 1 vs Type 2 Hypervisors

Thus far, the hypervisor described is catered for personal use and is called a type 2 hypervisor. Essentially, the host OS is installed on the hardware, with the (hosted) hypervisor running as an application on it: OS virtualisation. The hypervisor creates and runs the virtual machine(s) with the guest OS contained within them. It is important to note that these are typically slower because, as mentioned above, they depend on the system, so they can only use what they are allocated and must access it through the host OS, thus presenting latency issues. Security-wise, these are less secure — if an attacker compromises the host OS, they could use the host against it. Common examples you may have heard of are Oracle VirtualBox and VMware Workstation.

However, for big companies using huge servers, having to 'ask' the host OS for permission to control system resources is not feasible — they need to have direct access to the underlying hardware. Therefore, a type 1 "bare metal" or "native" hypervisor is used. It is given this



name because it is loaded directly onto the server hardware, controlling and interacting with the CPU, memory, and physical storage, and so is considered better-performing for enterprise. The security is much better because there is no OS between the hardware and the hypervisor that attackers could compromise. Apart from this, the concept is then much the same, with the guest OS installed on top, just without the 'intermediary' of the host OS. An example of a collection of guest operating systems for server hardware is Microsoft Server. It is important to note, however, that while there is no operating system, of course, the hypervisor needs components at the level of an operating system, such as a memory manager, which carries out tasks such as swapping processes both into and out of main memory as they are required. Examples of type 1 hypervisors are things such as VMware ESXi.

Some 'type 1' hypervisors are set up by default as what is technically a type 2 hypervisor. For example, you might run a version of Linux with no GUI — command line only — with a Linux Kernel-based Virtual Machine, or KVM, on top. KVM is a technology that is part of Linux, converting the physical servers into hypervisors that run the virtual machines. The interesting thing is that every virtual machine that is run is a Linux process and KVM can use features of Linux to improve performance, such as live migration — the ability to move running virtual machines between different physical hosts, i.e., servers, without any interruption to their running. But the Linux host still exists, so this could be considered either type 1, type 2, or none.

Snapshots vs. backups

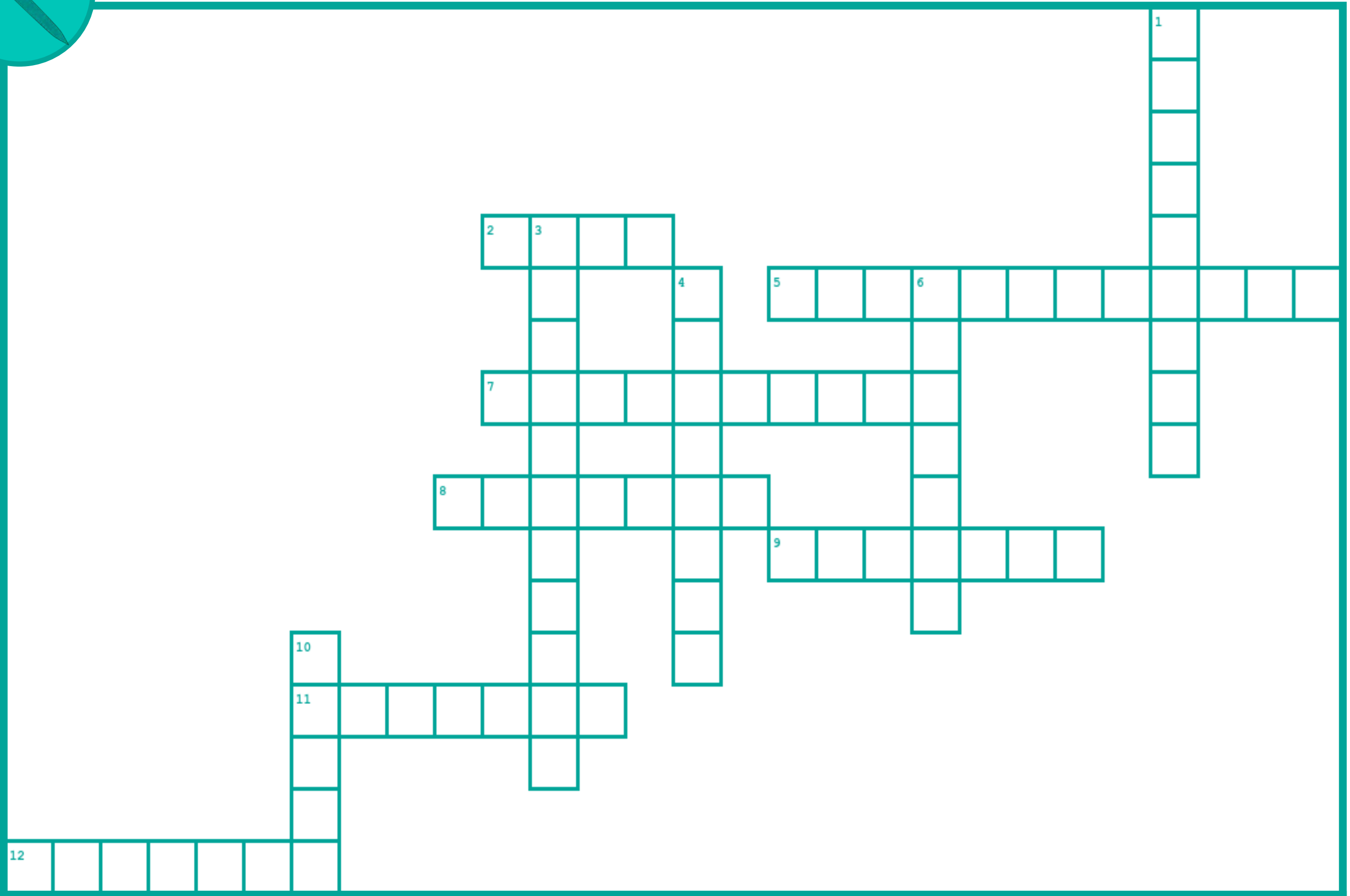
Just like with normal computer use, it is important to be able to recover data if something goes wrong. This can be done with snapshots or backups.

Snapshots preserve memory and configurations, among others, at a specific point in time. Much like how version control systems such as Git work, which track changes in computer files (as opposed to all the files each time), incremental delta files or change logs that track changes since the last snapshot are employed. To restore to a specific point in time, the snapshot, along with the archived ones before it, are combined as a chain of additions to the original to restore the virtual machine. One of the key uses of these is the aforementioned delta files, which are relatively small and so reduce the overall space that is required. The key fallibility of snapshots is that a change log system relies, of course, on — in this case — the original virtual disk. If this is corrupted or damaged, then there will be a problem. As such, snapshots are best used for things such as testing, because everything can be easily rolled back to the state before a new patch release, but not as the primary form of system recovery.

Backups are exact copies of everything in a VM that are, crucially, stored separately from the VM in another storage location. They are not dependent on the original virtual disk. Backups contain snapshots to make the operation run more smoothly, but of course, snapshots cannot be used as backups because they are dependent on the original virtual disk. As such, they are more useful for long-term storage, perhaps on separate devices, and can protect against things such as the corruption of data.

Edited by Jonathan Peter-Rajan

Issue 9 STEM Crossword



Across

2. A substance that reacts with bases to form a salt

5. The variety of life on Earth

7. The movement or circulation of a fluid due to variations in its density as a result of the transfer of heat within the fluid.

8. The combined mass of living or once-living organisms in a given area.

9. A chargeless nucleon

11. Change in momentum

12. Units are Volts per Ohm

Down

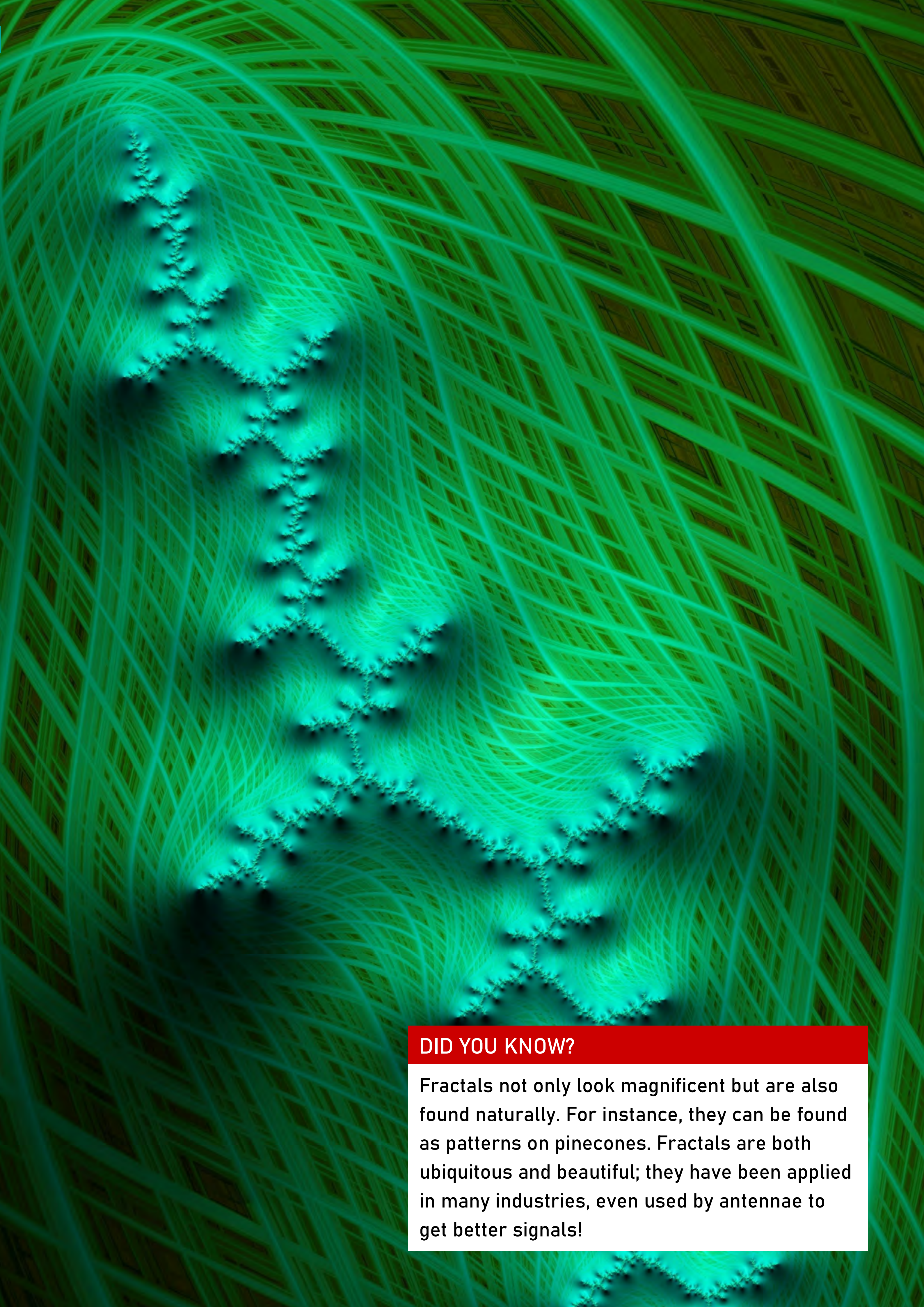
1. The movement of matter from a region of high concentration to a region of low concentration

3. An organelle in plant and algae cells where photosynthesis occurs.

4. Equal to Force per Area

6. It is defined as the ratio of an object's mass to its volume

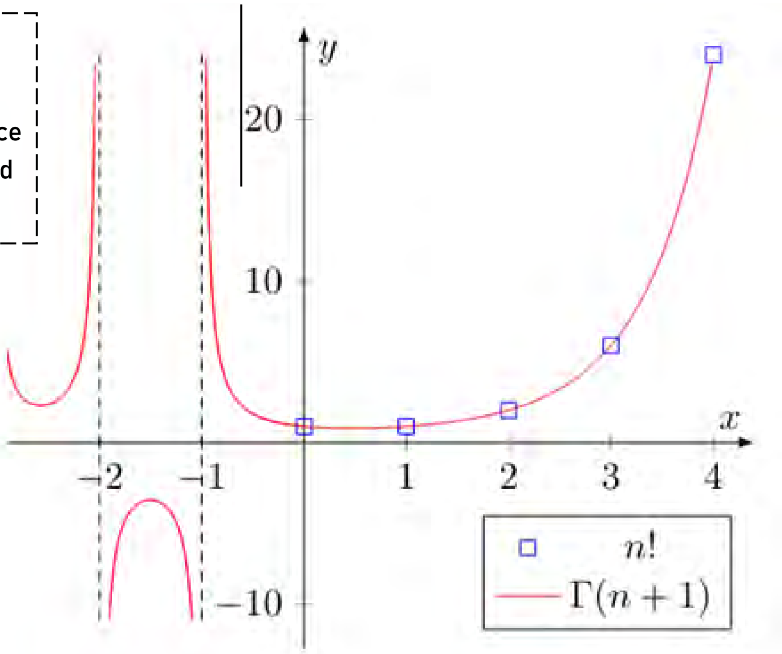
10. Exhibits both wave and particle properties



DID YOU KNOW?

Fractals not only look magnificent but are also found naturally. For instance, they can be found as patterns on pinecones. Fractals are both ubiquitous and beautiful; they have been applied in many industries, even used by antennae to get better signals!

The Gamma Function



What is Euler's gamma function?

Tarun Nair (Y13)

Let's take a look at the factorial.

The factorial is a function that, given an input n, returns the product of all the integers between 1 and n inclusive. For example, 5! is equal to the product of all the integers between 1 and 5 - that is, 1 × 2 × 3 × 4 × 5 = 120. From this, we note that the factorial is defined for all natural numbers.

It even works for n = 0. Consider the recursive formula for the factorial $n! = n \times (n-1)!$ and rearrange to get this:

$$(n-1)! = \frac{n!}{n}$$

This is a backwards step formula that, given an integer n and its factorial, gives the factorial of the previous integer. Using this and letting n = 1, 0! = 1, so the factorial is defined for n = 0 as well. This is all well and good… except that there seems to be a lot of numbers unaccounted for by this function. What about negative integers and non-integers? Let's try calculating (-1)! using that backwards step formula:

$$(0-1)! = \frac{0!}{0}$$

We've hit a snag. It turns out that negative integer inputs don't work with the factorial - and neither do non-integers. After all, trying to compute the product of all integers from 1 to 3.4 inclusive is obviously nonsensical. If we want to be able to apply the factorial to any number imaginable, we'll need to extend the range of inputs it can take. This is where the gamma function comes in.

What is Euler's Gamma Function?

Euler's gamma function, as it's formally known as, has countless different definitions in all sorts of different notations. Here's the first, and perhaps most fundamental:

$$\Gamma(z) = (z-1)!$$

It's this link that allows this function to extend the domain of the factorial: while the latter's domain is the set of non-negative integers, the gamma function's is the set of all complex numbers barring negative integers. We'll get back to this detail. Of course, there's also the business of calculating gamma function values given any input. The most common representation that allows us to do this is Euler's integral definition[1]:

$$\Gamma(z) = \int_0^\infty t^{z-1} e^{-t} dt$$

By the way, the t in the definition is a dummy variable [2]; it's merely used for the integration itself and disappears afterwards, so it doesn't have any real significance in defining the function.

This one isn't so simple. It's an improper integral as one of the limits of integration is infinite. This means that unlike proper integrals with finite limits, the convergence of this one (and thus getting a finite result) depends on how the function behaves as we take the limit. In turn this depends on our choice of z: some values cause the integral to converge - great news! But others may not.

This definition may resolve the problem of non-integer inputs, but the other problem of negatives still looms over us.

Unfortunately, as it turns out, the integral will only converge if the real part of the input is greater than zero. Remember that the domain of the function is more or less the set of all complex numbers, which have real and imaginary parts - for determining convergence we only care about the real part. Using the first definition of the gamma function, it should hopefully be easy to see why the factorial is undefined for negative integers.

An important use of the gamma function occurs in statistics, where it pops up in a very important probability distribution. It is continuous, like the normal distribution, and has the density function

$$f(x) = \frac{1}{\Gamma(k)\theta^k} x^{k-1} e^{-x/\theta}$$

where θ and k are parameters[3]. Fittingly enough, it's called the gamma distribution, and its job is to model the waiting time until a fixed number of events have occurred, like the waiting time in a queue given the number of people in front of you and the rate of service. At certain values of k, you even get other useful distributions, like the exponential and chi-squared distributions[4].

But how does the gamma function crop up in all of this? To see its purpose, let's see whether this distribution is valid by ensuring that its density function integrates to one across the support of the distribution (its "domain": all the values that this distribution can take) - in this case, from zero to infinity:

$$\frac{1}{\Gamma(k)\theta^k} \int_0^\infty x^{k-1} e^{-x/\theta} dx$$

One substitution later[5], we get:

$$\frac{1}{\Gamma(k)} \int_0^\infty u^{k-1} e^{-u} du$$

Does this seem familiar?

The whole integral is just $\Gamma(k)$ due to the integral definition of the gamma function so the whole area under the probability function is one, which is what we set out to prove. As a result, we can say that the gamma function in the fraction is a scaling term that facilitates this by canceling out the other gamma function term equated to by the integral term.

On another note, we have unveiled yet another use of the gamma function, especially when working with complicated integrals similar to the one above. In this example, we managed to transform this non-trivial integral into a more digestible form by using the integral definition, but in reverse. This means manipulating the integrand (the function being integrated) until it assumes the form in the definition, then re-writing the whole integral in terms of gamma.

So, there you go. Using the gamma function, we've filled in the gaps left by the much smaller domain of the factorial. The function acts as a sort of interpolation that connects the dots of the factorial, while preserving its properties. In addition, we got a useful probability distribution and a way to simplify integral expressions out of it.

Edited by Shanjeev Mathialagan

The Most Beautiful Equation

By Arnav Prasad (Y11)

"Logic is the foundation of the certainty of all the knowledge we acquire."—Leonhard Euler, a founding father of pure mathematics from the 18th century.

Through the elegance and extensive applicability of its arguments and formulae, mathematics forms bridges between once detached worlds. For those who learn the language, it has the capacity for magnificence equivalent to art, music and literature. Let us embark on a brief excursion to gain an insight into the subject's all-encompassing reach within our universe.

The equation we will examine is known as "Euler's Identity":

$$e^{i\pi} + 1 = 0$$

We will examine the nature of, seek proofs for and ultimately consider the utilisation of, in fields such as quantum physics, this identity and the formula from which it is derived.

We shall initially define the humble constant π. The transcendental number most commonly defined as the ratio of the circumference of a circle to its diameter has a value of approximately 3.14159… It is not the root of any integer polynomial[1] and thus not an algebraic number of any degree. Euler's number is also transcendental, denoted by the letter *e*. It is approximately 2.71828… and can be defined in a plethora of means:

These are all useful for different

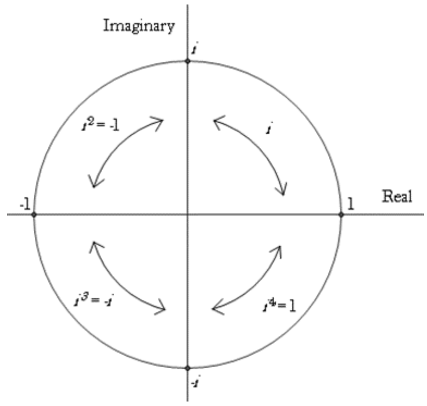
$$e = \lim_{n\to\infty}\left(1+\frac{1}{n}\right)^n = \lim_{t\to 0}(1+t)^{\frac{1}{t}}$$
$$= \sum_{k=0}^{\infty}\frac{1}{k!}$$
$$= \lim_{n\to\infty}\frac{n}{\sqrt[n]{n}}$$
$$= 2 + \cfrac{1}{1+\cfrac{1}{2+\cfrac{1}{1+\cfrac{1}{1+\cfrac{1}{4+\cfrac{1}{1+\cfrac{1}{1+\dots}}}}}}}$$

applications; (1) is used for studying limits and growth rates and (2) finds use in proving the transcendence of *e*, etc[2]. Finally, we meet *i*, the imaginary unit, defined as

$$\sqrt{-1}$$

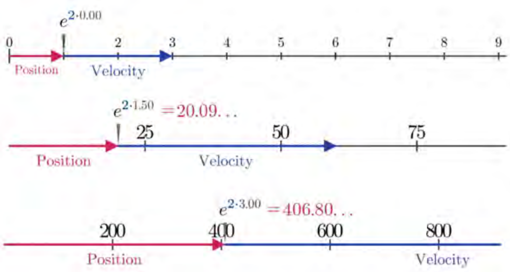
It forms the complex plane—representing real numbers by displacement along the *x*-axis, and imaginary numbers along the *y*-axis. This allows us to visualise complex numbers (in the form *a + bi*) as points with coordinates (*a*, *b*).

The acknowledgement we require to begin our proof is the effect of multiplying a vector by *i* on the complex plane. The multiplication of any real number *x* by i^2 facilitates its multiplication by -1 (since *i* is defined as the root of negative one) and thus a rotation of 180°. Therefore, multiplication of this vector by *i* causes a 90° anticlockwise rotation; multiplication by higher powers of *i* is as follows:



(Alternatively, the 'argument' ϕ of *z* is increased by 90). We then recognise that $\frac{d}{dt}e^t = e^t$ arguably the defining feature of this function. Illustrating the function with a physical model,

e^t is the position of a point on a real number line as a function of time, *t*. Thus, the velocity of this point—the derivative of



displacement—is always equal to the position, and the condition

$$e^0 = 1$$

means this point starts at displacement one.

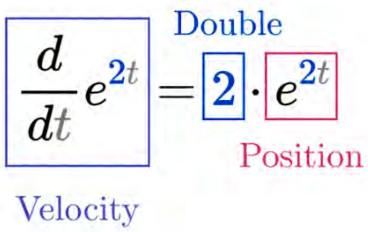
The point accelerates and the function exhibits exponential growth:

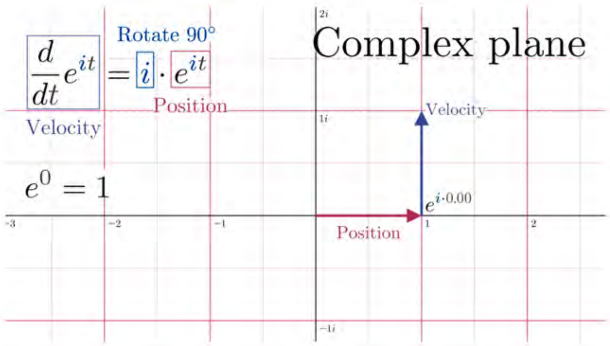
The chain rule dictates that multiplying our exponent by a constant *k* causes the derivative (and thus velocity) of the function to be *k* times the original, e.g. substituting *k* = 2 gives:

We substitute *i* into $\frac{d}{dt}e^{kt} = ke^{kt}$ for *k*, the derivative

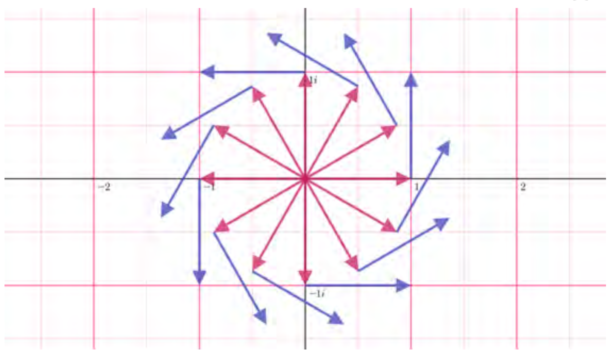
of the displacement e^{it} is now: ie^{it}

Thus rotating the vector 90° anticlockwise using the complex plane:





[3]



Hence, for any displacement *e* gives, the velocity at this time will be a 90° rotation of itself:

Subsequently, we create a vector field with this information. At

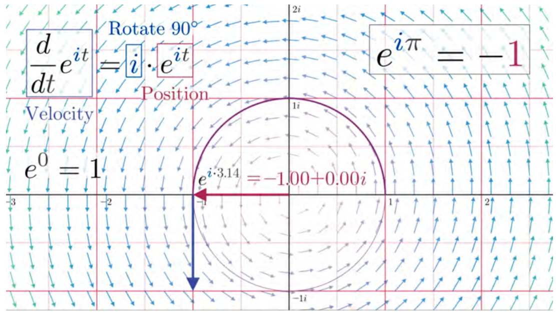
$t = 0 \quad e^{it} = 1$

The trajectory of the vector is rotational movement around the unit circle at a speed of 1 unit/s. After π seconds (when *t* = *π*) a distance of *π* radians has been traced around the origin. Therefore:

Now for certainly the most challenging step in our proof. We add one to both sides of the equation and are left with:

$e^{\pi i} + 1 = 0$

This equation is far from a mere party trick. Aside



from displaying a profound connection between the most fundamental numbers in mathematics, Euler's formula (of which Euler's identity is simply a case, where *θ* = *π*) establishes the fundamental relationship between trigonometric functions and the complex exponential function in complex analysis. Euler's formula states that:

$$e^{i\theta} = cos(\theta) + isin(\theta)$$

Many proofs for Euler's formula exist, involving concepts such as the Maclaurin series for sine and cosine, polar coordinates, and power-series expansions[4].

It is worth noting the pertinent applications of this formula in fields that permeate everyday life. One such example is the use of alternating current (AC) in almost all electronic devices, including mobile phones, desktop computers, etc. This may be in the form of power cables, or a resonating component such as an inductor. Since AC is treated as a complex wave, it is written in the form:

$$f(x,t) = e^{ik(x-ct)}$$

This is a special, propagating wave solution of Euler's formula which is useful for modelling many wave phenomena.[5]

Look around yourself. Any light from electronic sources likely requires Euler's formula—it has revolutionised electrical engineering and physics. Our short expedition into the elegant domain of pure mathematics has come to an end, and we have gained invaluable insight into the practical applications of the most beautiful equation in mathematics.

Edited by Jonathan Peter-Rajan

"17 EQUATIONS THAT CHANGED THE WORLD"

by Prof. Ian Stewart

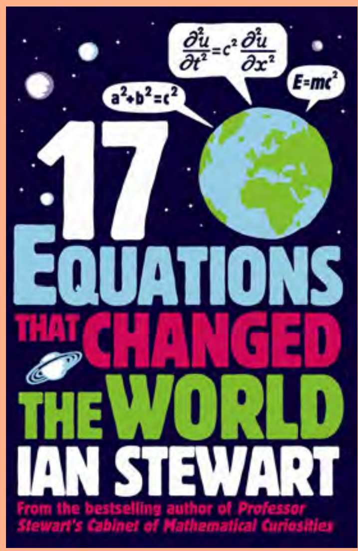
In '17 Equations That Changed The World', Professor Ian Stewart tells the story of the ascent of humanity through these seventeen equations he has chosen to explore. Equations show a powerful correspondence between mathematics and the nature of our universe, modelling complex patterns found everywhere in the outside world. Some may claim that language can express these patterns with more clarity but arguably they are not as precise as the symbols that equations consist of - and hence are unable to offer an effective route to deeper aspects of reality. In this book, Stewart proves that equations have been crucial to the advancement of human civilisation, whether we realise this or not.

The equations chosen range from topics such as trigonometry to more complex ones such as waves and fluid dynamics. In each chapter, Stewart clearly outlines each equation, fleshing out what each part of it means; the significance of the equation; and the crucial developments it led to. In earlier chapters, the equations were often easier to follow but as I progressed, they became increasingly more difficult to understand, introducing high-level concepts such as partial derivatives and complex numbers, which were more challenging to grasp; I think that less of the book could have been focused delving deep into enigmatic elements of the equations so that the focus could remain on their implications, whilst still enabling the reader to appreciate the mathematics behind each of them. However, Stewart does make the mathematics more digestible by skilfully interweaving the mathematical details of each equation with historical details, explaining the process by which each equation was formed and the history made as a result.

One of the sections I found most interesting was 'Good vibrations' - the eighth chapter, outlining the wave equation, a result of the work of Jean Le Rond d'Alembert. This part of the book caught my interest due to one simple phrase - 'Mathematics thrives on simplicities'. It sums up how it is all too easy to dive into a complicated problem and immediately try and solve it without any second thought but often maths and physics problems are solved as a result of breaking down a problem, or creating a simpler model to then adjust for more intricate calculations.

In this chapter, Stewart explores the idea of how mathematicians create models to offer an entry route into more complex problems. These 'toy' models (as mathematicians refer to them) led to the present day where passenger jets, artificial satellites and radio are all commonplace but none of these things could have been achieved if mathematicians had not started to model how the string of a violin vibrates, using a model that was unrealistic even for a violin.

Something else that caught my attention was the continuity of the equations. The discovery of a new equation rarely disproves another one; instead, they build on one another to reveal more and more about how the universe functions. An example of this is how Einstein developed the Newtonian understanding of the universe through his theory of relativity, linking the concepts of space and time whereas Newton had kept these separate, following the Euclidean geometry of space.



Across all the chapters, I frequently found the sections exploring the applications of each equation to be the most interesting. I discovered that equations such as Pythagoras's Theorem, which I have known for many years, have uses that I do not usually consider - such as surveying and creating accurate maps. It was also intriguing to learn how such simple equations had complex geometric proofs and contributed to theories such as special and general relativity.

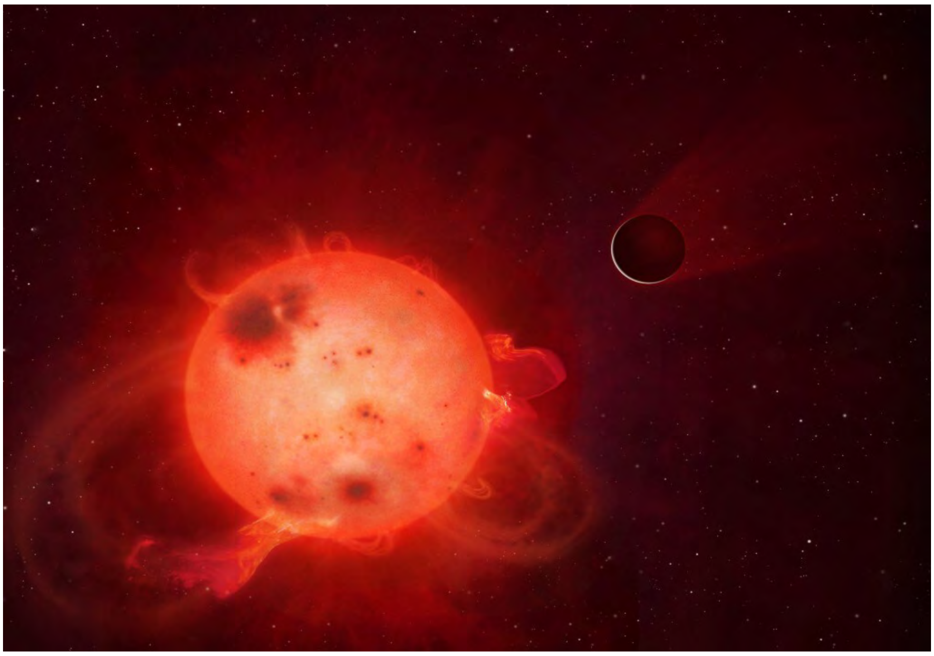
The applications of the normal distribution were of particular interest to me as they related to a work experience I did in the actuarial department of a reinsurance firm, where probability is vital to calculate how much capital must be set aside to pay out claims, in order to make a profit from insurance premiums. The bell curve (normal distribution) is vital for this and for many other uses, where probability theory is used to make predictions. Some applications of the normal distribution can be particularly controversial - for example, it could be used to predict how many suicides would take place in a population. It seems strange to predict who exactly will kill themselves and when as this appears to contradict free-will. But in a sufficiently large population, the normal distribution can accurately predict this in the context of various factors such as financial problems, religious background and mental state - due to Bernoulli's Law of Large Numbers, a large population results in highly accurate predictions.

Overall, Stewart successfully argues for the importance of equations in society - his thorough research, deep understanding of the equations, and his light-hearted humour ensures that '17 Equations That Changed The World' is a challenging but eye-opening read, allowing the reader to appreciate the beauty of the symbols which govern the world we live in.

By Edwin John (Y12)

DID YOU KNOW?

Incandescent light bulbs were not actually invented by Thomas Edison! Prior to Edison's designs, twenty-three other bulbs had been developed. For example, in 1809, Sir Humphrey Davy produced the first ever electric arc lamp. Later, in 1820, Warren De la Rue developed the first ever incandescent light bulb.



The Stars at the End of Time

By Biranavan Lambotharan (Y12)

The most ancient surviving stars are red dwarves, and the final stars to fuse Hydrogen before the heat death of our universe will also be red dwarves. Though invisible to the naked human eye, red dwarves are the most common stars in our galaxy. This article shall uncover the intriguing secrets hidden in these dim crimson dots scattered throughout the cosmos.

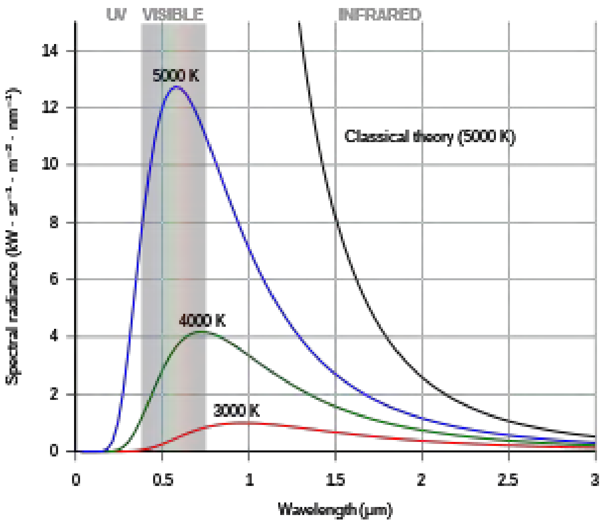
Proxima Centauri, the closest star to our own which is also a red dwarf with a confirmed planet

What are Red Dwarves?

Red dwarves comprise over 75% of known stars in the Milky Way [1] and are the smallest and dimmest stars to generate thermal energy through the nuclear fusion of Hydrogen into Helium in their cores. They range from 0.08 to 0.6 solar masses, comprising the M spectral class. They are relatively cool and have a low stellar flux, with maximum surface temperatures of around 3900K [1]. Red dwarves are the longest-lived of all stars. For context, the duration of our Sun's main sequence is ten billion years.

Unique Processes

There are two reasons for red dwarf longevity. Firstly, red dwarves redistribute Hydrogen through convection [2]. The main sequence for other stars may end once the little Hydrogen present in the core is depleted, but convection inside red dwarves means Hydrogen fusion can continue far longer as Hydrogen from the outer layers is brought into the core and fused. Furthermore, due to lower temperatures and pressures inside the star, thermonuclear fusion is much slower than in higher-mass stars, so Hydrogen reserves are fused much more slowly: at lower pressures and temperatures, Hydrogen nuclei collide less frequently, and it is much harder to overcome electrostatic forces of repulsion between them.



Blackbody Radiation Characteristic of Red Dwarves Shown in Red

The electromagnetic spectra of these stars peak in the lower-energy infrared frequencies invisible to the human eye, with visible light emissions leaning towards the red end of the spectrum to give red dwarves their name.

The small size and lack of internal layering in red dwarves cause them to rotate at much faster speeds than other stars, resulting in a greater magnetic field strength and prevalence of extreme magnetic activity; frequent stellar flares of ionising UV and X-ray radiation occur, especially in younger stars [3].

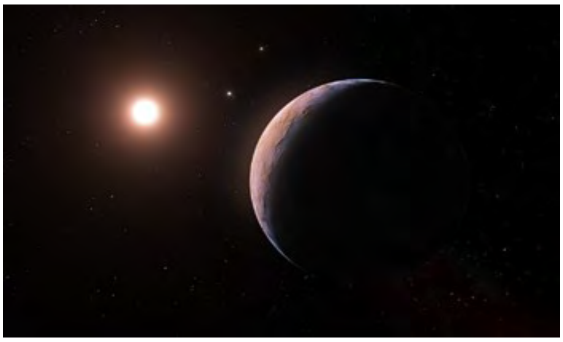
Life Cycles

Red dwarves form from nebulas of dust and gas left over from previous supernovae before then coalescing into stars with sufficient internal temperatures and pressures to undergo nuclear fusion. They then fuse Hydrogen through their main sequence for trillions of years.

Since red dwarves have lifespans older than the age of the observable universe, red dwarves have yet to be observed at advanced life cycle stages- we can only model what could happen next.

One such theory is that of the blue dwarf [4] - created towards the end of a red dwarf's life. As stars begin to run out of Hydrogen, they must increase their radiative rate to maintain the equilibrium between gravitational contraction and thermal expansion. Red dwarves collapse inwards with surface temperatures rising to up to 8600K- causing them to shine blue until fusion stops completely. They then shed material to form white dwarves- tiny stellar remnants which will then cool slowly to form the dense black dwarves.

Due to their monumental lifespans, red dwarves are very likely to be the last shining light of fusion before the universe goes dark and are the oldest stars we can observe today- giving us an insight into the universe's history from start to finish. One of the most ancient surviving stars is HD140283 (known as Methuselah), a red dwarf with an age of at least twelve billion years [5]. Since all red dwarves contain heavy elements such as Carbon and Iron in their infrared spectra, it is unlikely that they were the first stars to form, since all elements other than Hydrogen, Helium and Lithium only formed by fusion after the Big Bang- but they will be the last to live.



Artist's Impression of Proxima Centauri D

Habitability Potential

Red dwarf systems are of great interest in finding planets habitable for humans and extra-terrestrial life, since they are both the longest-lived and most ubiquitous of stars. Examples of interest include TRAPPIST-1 with at least three earth-sized planets in its potentially habitable zone- and Gliese 581. However, some factors cast doubt on the habitability of such systems; red dwarves perhaps have no habitable zones at all.

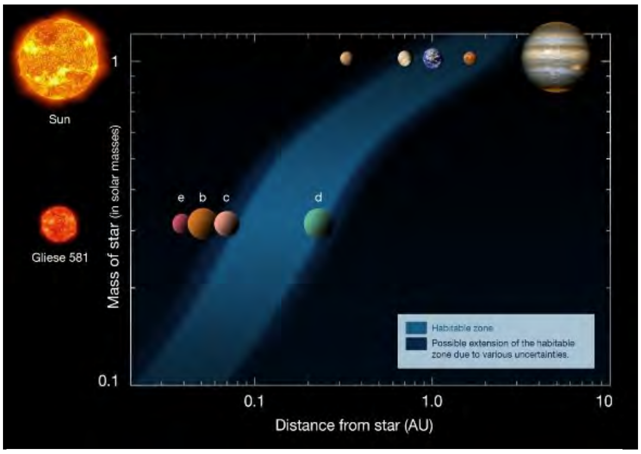


Diagram of Habitable Zones

Electromagnetic flares can ionise molecular Oxygen, potentially stripping planets of their atmospheres [6] - although these may be emitted from stellar poles rather than across the planetary orbital plane. The minimal stellar flux of red dwarves means planets must orbit extremely close to stand a chance of receiving enough heat to sustain liquid water, leading to tidal locking where planetary rotation halts. This creates an ultra-hot day zone and an ultra-cool night zone on the planet's two sides. There may, however, be a 'twilight zone' in the middle with liquid water, and a strong atmospheric or oceanic circulation [7] could redistribute heat across the planet to negate this effect altogether. Habitable planets could exist around red dwarves, but the odds are stacked against them.

To conclude, red dwarves are the most long-lived, ancient, and closest of all stars, making up for their lack of luminosity in sheer intrigue as windows to the very beginning and the very end of time itself. If habitable planets around red dwarves exist, they could be the first directly observed by humanity and perhaps the final homes of life in our universe before the lights finally go out.

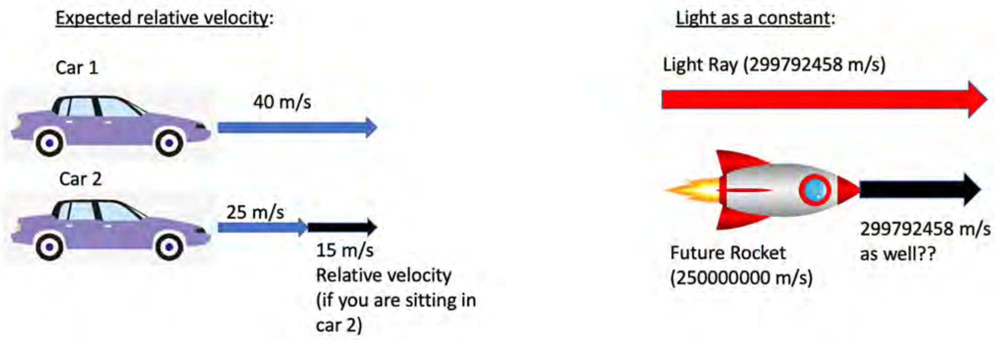
Edited by Tejas Gadkari

Bending Time

By Advait Bhatia (Y11)

Scottish Physicist James Clerk Maxwell published his "Dynamical Theory of the Electromagnetic Field" in 1865, which revolutionised the understanding of electromagnetism. Maxwell's equations also showed the existence of an 'electromagnetic wave', which were formed by electric and magnetic fields. These led to Maxwell discovering the speed of these waves - 299,792,458 m/s in a vacuum[1]. This discovery was that of light, and went under the radar for a while, until it was finally picked up by a physicist working in the Swiss Patent Office, of the name Albert Einstein.

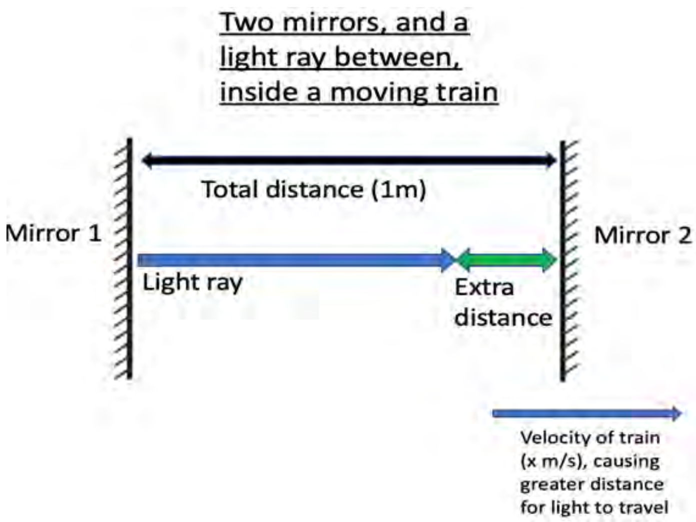
The idea of a 'constant', unchanging speed of light was a problem - the leading train of thought on motion, known as Galilean Relativity, stated that it was impossible to say whether an object was moving or at rest[2]. In other words, motion could only be described relative to another object, not in absolute terms e.g., a car on a motorway travels at 70 mph relative to the road beneath. However, the speed of light being an absolute constant has odd



From this we can see the apparent absurdity of this notion - the person in car two would measure the velocity of car one (relative to itself) as 15 m/s. However, as the speed of light is a supposed constant, regardless of your own velocity, you will always measure light's speed as the same (as people in the rocket would).

Einstein took this idea a step further, by devising a thought experiment.

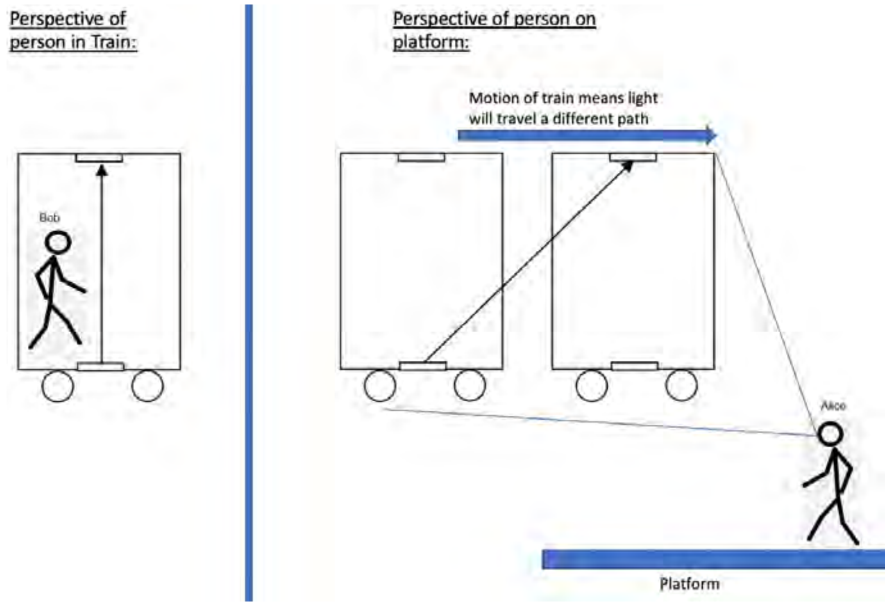
A moving train (relative to the track) contains a device known as a light clock, in which light is bouncing between two mirrors to represent time, and an observer who is stationary, also relative to the track.



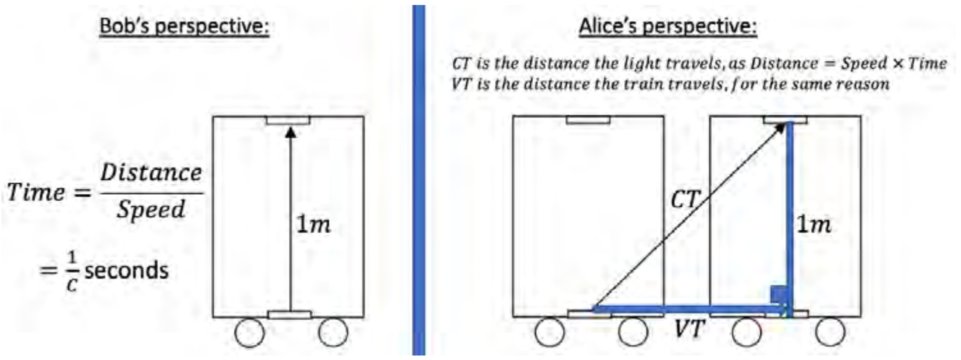
Because the speed of light is constant, it will not be imparted momentum by the moving train (unlike other waves, such as sound). This means that light must travel an 'extra distance', as compared to a stationary train. Using speed = distance/timeslower for people on the train, compared to on a platform - the speed, 299,792,458 m/s, is constant (due to Maxwell's equations), but the distance has clearly increased. Therefore, to compensate for this, the time must decrease (relative to the stationary observer). Take a moment for this to sink in: We have just shown that time actually slows down during motion, simply using the basic speed equation!

Einstein then took this even further to show exactly how much the time has slowed down. Once again, the light clock is placed in a train, but is rotated by 90°. A person, called Bob (as is physics naming convention), is on the moving train, and Alice, is stationary on the platform (both relative to the tracks):

It is evident from this that what Bob sees is not the same as what Alice sees - motion is causing a discrepancy in observation. Let's say that the distance between the two mirrors is one metre, the velocity of



the train is v m/s, and the speed of light is c m/s. This leads to the distance travelled by the light being ct, and the distance travelled by the train being vt.



$$(ct)^2 = 1^2 + (vt)^2$$
$$c^2t^2 = 1 + v^2t^2$$
$$c^2t^2 - v^2t^2 = 1$$
$$t^2(c^2 - v^2) = 1$$
$$t^2 = \frac{1}{(c^2 - v^2)}$$
$$\therefore t = \frac{1}{\sqrt{(c^2 - v^2)}}$$

So, from Pythagoras' Theorem, we know that for the moving Bob, the time for one ray to travel is simply $1/c$ seconds, but for Alice, that same ray takes $\frac{1}{\sqrt{(c^2-v^2)}}$ seconds, where v is the (relative) velocity of the train. Thus, the faster the train, the longer the time taken for the ray to travel one metre. I find this simply amazing - time actually slows down by a measurable amount at a given velocity. Finding the ratio of these two values gives us the Time Dilation or Lorentz factor [3]:

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

This discovery amazed the world and forged a path for Einstein to uncover the famous equation $E = mc^2$ in his paper on "Special Relativity" in 1905. In day-to-day life, this effect is tiny. A train travelling at 300 kmph would only experience 0.0000000000039 extra years if it travelled for 100 years, according to a person on the platform[4]. Fortunately for scientists, this equation is essential for particle accelerators: muons (a type of particle) decay in only 2.2 microseconds. However, by accelerating them to 99.94% of the speed of light, this effect can be seen, since they survive for over 60 microseconds, a perfect match with the theory's predictions[5].

Whatever your view of Einstein's theories, space and time, the beauty and relative simplicity of time dilation are impossible to ignore. They have reshaped the belief that time is static and unchanging. Instead, it is something truly fascinating - flexible and continuously changing.

Edited by Youyou Yu

Jet Fuel can Extinguish Matches

By Arko Mukherjee (Y12)

When a plane crashes, the first priority of survivors is to remove oneself from the perimeter of the wreckage in order to avoid being near a probable explosion, caused by the aviation fuel catching fire, as it did in the case of Crossair flight 3597, Air Canada flight 797[1] (following an initial lavatory fire), and several others. However, the NTSB demonstrated, can extinguish a candle, just as water does.[2]

Wreckage of Trans World Airlines flight 800

There are several types of aviation fuel for both military and civilian purposes, which offer different properties, such as ease of ignition, energy density, and melting points. Most aviation fuels are based on the kerosene faction extracted from crude oil, with a few additions such as antioxidants that prevent the corrosion of the sides of the fuel tank containing the fuel.[3] The trend of relative ease of ignition is that fractions containing larger carbon chains in their molecules are harder to ignite, but also more energy is given out per mole of these larger molecules in combustion. Therefore, in its liquid form, kerosene can extinguish a match when the match is dropped in it from a low height by disallowing the fire access to oxygen. The match must be fully inserted into the liquid fuel.[2] However, when vaporized, aviation fuel is very flammable. In a turbojet engine, the fuel is sprayed as a fine mist into compressed air that is at a high pressure, making it very flammable and therefore allowing combustion to occur and the engine to function. Vaporization is also why when the exact same match is held above the fuel's surface, a bigger flame is produced. Fuel vapor is present near the surface of the fuel, being a mixture of a gaseous form of the fuel and air, similar to the mixture present in the combustion chamber. This easily catches fire, producing the larger flame. Vaporization happens due to evaporation of the fuel, the rate of which is increased by any heat taken in from the surroundings. A larger amount of energy must be taken in to vaporize a larger mass of fuel, as stated in the equation for specific latent heat (SLH) of vaporization:

SLH = Energy Transferred / Mass

where specific latent heat is a constant (ignoring different fractions) , and therefore as mass increases, the energy that must be transferred must also increase), and therefore, a smaller mass of fuel evaporates faster to produce a flammable vapor than a larger amount of fuel . This is dependent on surface area, so a larger surface area (which is normally associated with a smaller volume) means the evaporation rate is faster. A larger mass of fuel also occupies a greater volume than a smaller mass of fuel in a fuel tank, reducing the space remaining in the fuel tank, called ullage, where fuel vapor forms.[4] This can be seen through the accident of TWA 800,[5] which was destroyed by an explosion originating in its nearly depleted centerline fuel tank, however in the case of China Airlines 120,[6] which exploded while parked at a gate shortly following engine shut-down, the more conventional belief that more fuel leads to bigger explosion would hold true . The aircraft had a four-centimeter-wide breach in the right -wing fuel tank (nearly depleted as the incident occurred after a flight), through which escaping fuel came into contact with the hot number two (right) engine, boiling the fuel to form an explosive vapor of a mixture of air and fuel, which did later ignite. in this case, as the engine temperature was above the boiling point and autoignition point for the fuel (210 degrees Celsius for Jet A fuel), any escaping fuel coming into contact with the engine would spontaneously combust, and would vaporize almost immediately, therefore not providing the "smothering" effect that cool liquid fuel provides.

Currently, the military uses an inerting system in its fuel tanks that reduce the concentration of flammable oxygen in the fuel tank, while increasing the concentration of non- reactive nitrogen, which was being developed by NASA to reduce the weight and size of such a system.[7]

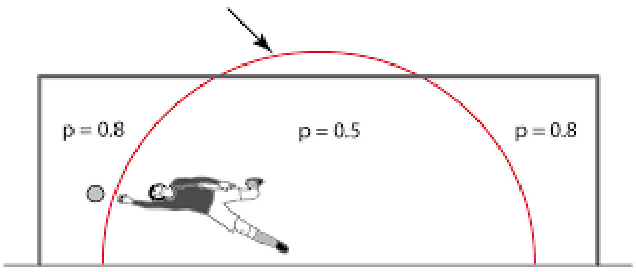
Edited by Youyou Yu

The Physics Behind Taking the Perfect Penalty

By Dave Meninson Babu (Y11)

Penalty shootouts. The dreaded moments after 120 gruelling minutes of football where individuals from two teams take turns at attempting to score against the opposition's goalkeeper from 12 yards out from the centre of the goal to win the deadlocked match. One kick can make a country bounce with joy and another country crumble with despair. One kick can build a player's legacy or tear it to the ground. One kick can decide the winners of prestigious tournaments. There are many football players in the world who can score great penalties like Lionel Messi and Cristiano Ronaldo, who score vital penalties in the extremely high-pressure situations, but how do they strike the perfect penalty almost every time?

When we see their penalties, we see the results of various processes that involve physics. The ball is firstly at rest since, according Newton's first law of motion, every object will remain at rest or in uniform motion in a straight line unless compelled to change its state by the action of an external force. The player will provide this external force causing the ball to move[1]. The penalty taker will accelerate towards the ball, increasing their velocity.[3] When the player is in front of the ball, they will firmly plant their non-kicking foot beside



Diving envelope in a penalty kick

the ball to form a solid base[2]. By swinging his hips around the hip joint, the kicker brings the kicking leg forward in a circular motion with a small bend at the knee[3]. When the player's foot is in contact with the ball, they snap their knee straight in a whip like motion which causes the player's leg to accelerate causing a greater force on the ball[3]. This is because Newton's 2nd law states that force is directly proportional to acceleration. After coming into contact with the ball, the player must follow through, increasing the time the ball is in contact with the large force causing the ball's velocity to increase.

Due to the fact that momentum is conserved, the change in momentum of the ball will be equal to the change in momentum of the player's leg. Therefore, the higher the mass and velocity of the players leg before the collision with the ball, the higher the momentum of the ball.

This is important as speed is especially important to take a good penalty since the average height of a premier league goal keeper is 6ft 3in and if the ball is not struck firmly, they will be able to reach it[2]. The direction of the ball is determined by where the ball is struck[1]. When the ball is kicked, it rotates on its axis and the direction of the rotation depends upon where the ball is kicked. The side of the ball where air moves in the opposite direction of the rotation, experiences high pressure[1]. Whereas, the side of the ball where the air moves in the same direction of the rotation, experiences low pressure[1]. The difference in pressure causes the ball to curve to the low-pressure side[1].

Therefore, the ball must be struck in a way where the ball curves in to the corner of the goals away from the goal keepers reach.

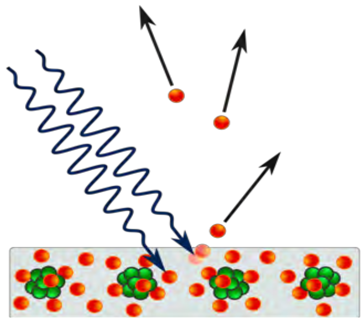
This shows that the probability of scoring increases as the player aims away from the 'envelope' as it is harder for a keeper to reach those areas[2]. However, shooting straight down the middle can also be effective as most keepers do not stay in the middle of the goal[2]. Now you know how top players take great penalties so next time you take a penalty, keep in mind how and where to strike the ball.

Edited by Youyou Yu

The Photoelectric Effect

By Padmesh Ayyappan (Y12)

On the 14th February, 1672, English Physicist Sir Isaac Newton stated that the 44th trail in a series of experiments he had previously conducted proved that light was made of particles. Simultaneously, English polymath scientist Robert Hooke stated that light was made of waves.



EM radiation hitting a metal plate (ejected photoelectrons)

Only a few years later, experiments supplemented by Maxwell's equations (which describes lights behaviour as a wave), proved that Hooke was right, settling the raging battle. On August 23rd 1921, the Nobel Prize was awarded to German-born theoretical physicist Albert Einstein, with his exalted explanation of the photoelectric effect, reassuring the burning, age-old debate of what light is made of [3].

But how was it discovered? When light was shone on two adjacent cables, electrons jumped from one cable to the other. It was thought that waves of light made atoms vibrate until they ejected an electron. However, careful inspection revealed the phenomenon only happened for light of specific wavelengths. For others, no electrons jumped at all.

The photoelectric effect should have work regardless of the type of light – clearly something was wrong. Einstein then thought how if light was neither a particle nor a wave, then it could be made of both. This led him to formulate a hypothesis of light being made of 'wave-packets', which is now known as photons.

Where KE_{max} is maximum kinetic energy of the photoelectron; h is Planck's constant; f is the frequency of the incident light and W is the work function of the metal - the minimum amount of energy required to liberate an electron to infinity form the surface of a metal.

$$W = hf_0 \qquad KE_{max} = hf - W$$

The equations that Einstein wrote regarding his hypothesis helped to consolidate how light was sometimes a wave, sometimes a particle and sometimes both! This opened an exciting new field for quantum physics.

But how does it work? When light exceeds a certain frequency, electrons are 'dislodged', regardless of the light's intensity or duration of exposure. Since a low-frequency beam at a high intensity does not build up the energy required to produce photoelectrons, as would be the case if the light's energy accumulated over time from a continuous wave. Hence, Einstein described light as photons [1].

Emission of conduction electrons from typical metals requires a few electron-volt (eV) light quanta, corresponding to short wavelength visible or ultraviolet light [1]. Photons have a characteristic energy – called photon energy. When the conduction electrons absorb the energy of a photon and acquires more energy than its binding energy, it is likely to be ejected [2].

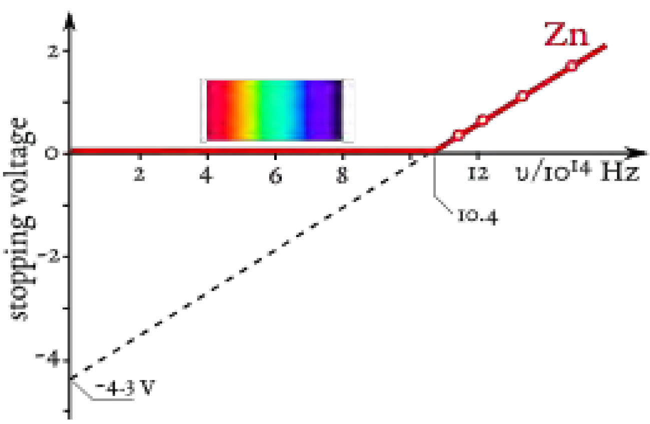
If the electrons cannot absorb enough energy, then it won't be able to escape.

If the electrons cannot absorb enough energy, then it won't be able to escape. An increase in the intensity of low-frequency light would increase the number of low-energy photons, but the change will not create any photon with enough energy to dislodge an electron. Part of the acquired energy is used to liberate the electron and the rest is transferred to the electron's kinetic energy stores. So, if the light does not have enough energy to free the electron, then it just vibrates more – a one to one ratio of interaction is present between electrons and photons of the incident light [3].

This also links well in with quantum physics: Electrons in different materials occupy many different quantum states with different binding energies. Thus, the emitted electrons will have a range of different kinetic energies. The electrons from the highest occupied states will have the highest kinetic energy. In metals, those electrons would be emitted from the Fermi level (E_f).

Each photon carries energy hf that is proportional to the frequency f of the corresponding electromagnetic wave. The maximum kinetic energy of the electrons that were delivered this much energy before being removed from their atomic binding is:

$$KE_{max} = hf - W$$



Maximum kinetic energy as a function of the frequency of light on zinc

Therefore, the equation becomes:

$$KE_{max} = h(f - f_0).$$

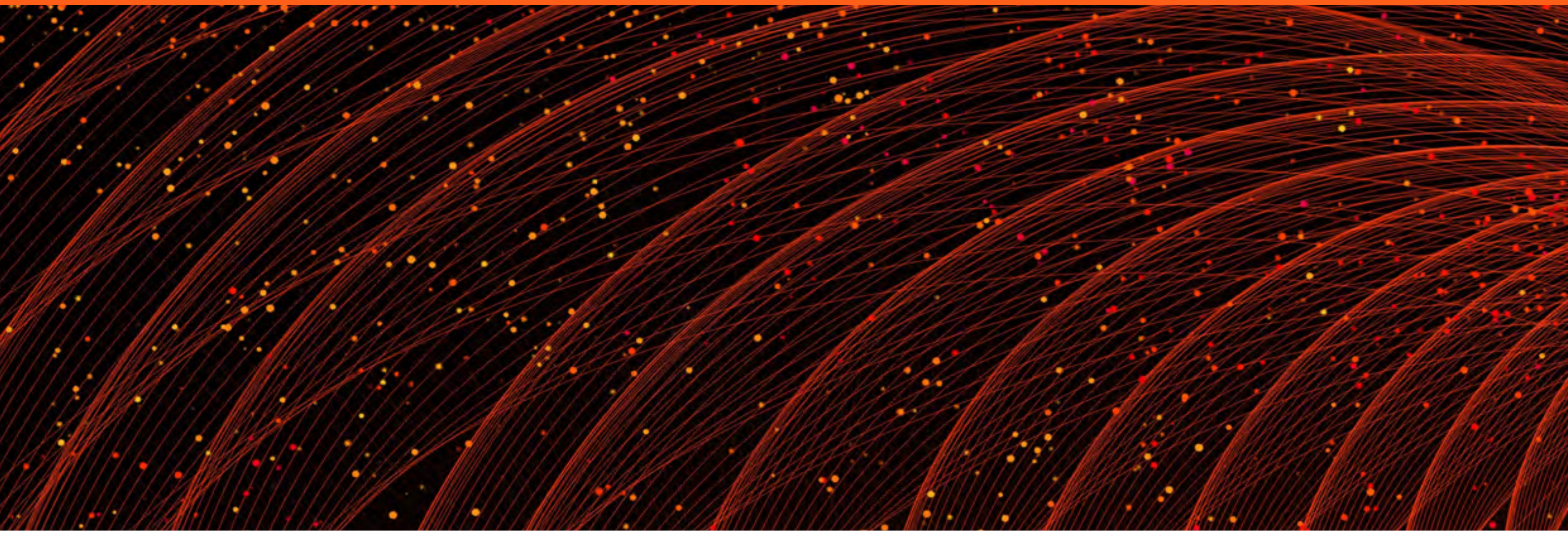
KE is positive and $f > f_0$ for the photoelectric effect to occur. The frequency f_0 is the threshold frequency of the given material, which is the minimum frequency of radiation that will lead to the photoelectric effect [5].

This effect is crucial in many applications. When a spacecraft is exposed to sunlight, the photoelectric effect causes the spacecraft to develop a positive charge. Whilst this occurs, other parts of the spacecraft develop a negative charge from nearby plasmas and this creates a high potential difference, which can result in the discharge of the imbalance through electrical components.

Moreover, light from the Sun hitting lunar dust causes it to become positively charged from the photoelectric effect. Since each dust particle has like charge, the charged dust then repels itself and lifts off the surface of the moon by electrostatic levitation. This was first photographed by the Surveyor program probes in 1960.

Finally, the binding energy can be found out by shining a monochromatic X ray of a known energy and measuring the kinetic energies of the photoelectrons. Photon spectroscopy measurements are usually performed in high-vacuum environment because the electrons would be scattered by gas molecules if they collide. The concentric hemispherical analyser is a typical electron energy analyser. The machine uses an electric field between two hemispheres to change the trajectories of the incident electrons depending on their kinetic energies.[2]

Edited by Tejas Gadkari



The Quantum Measurement Problem

By Ramin Ryan (Y13)

The Quantum Theory developed by numerous physicists in the early 1900s was one of the greatest scientific advancements of the 20th century. It has allowed us to better understand the interactions between light and matter, and their basic constituents. Although there is much more to be discovered, it has proven the test of time and the experimental proof to support it is astounding. Given that, as late as 1889, Hertz asserted that 'the wave theory of light is from the point of view of human beings a certainty', it is surprising how quickly this view was transformed, in the span of just 50 years.

However, at the heart of the tremendously successful quantum theory, there remains a fundamental issue - the infamous measurement problem. The measurement problem describes the inability of theory to describe what occurs after and during the act of observation of a quantum mechanical system. Mathematically, it is the question of how, or if, wave function collapse occurs. To explore the measurement problem, we must first understand the Schrödinger equation, of which there are two formulations – here is the time-dependent form:

$$i\hbar\frac{\partial}{\partial t}\Psi = \hat{H}\Psi$$

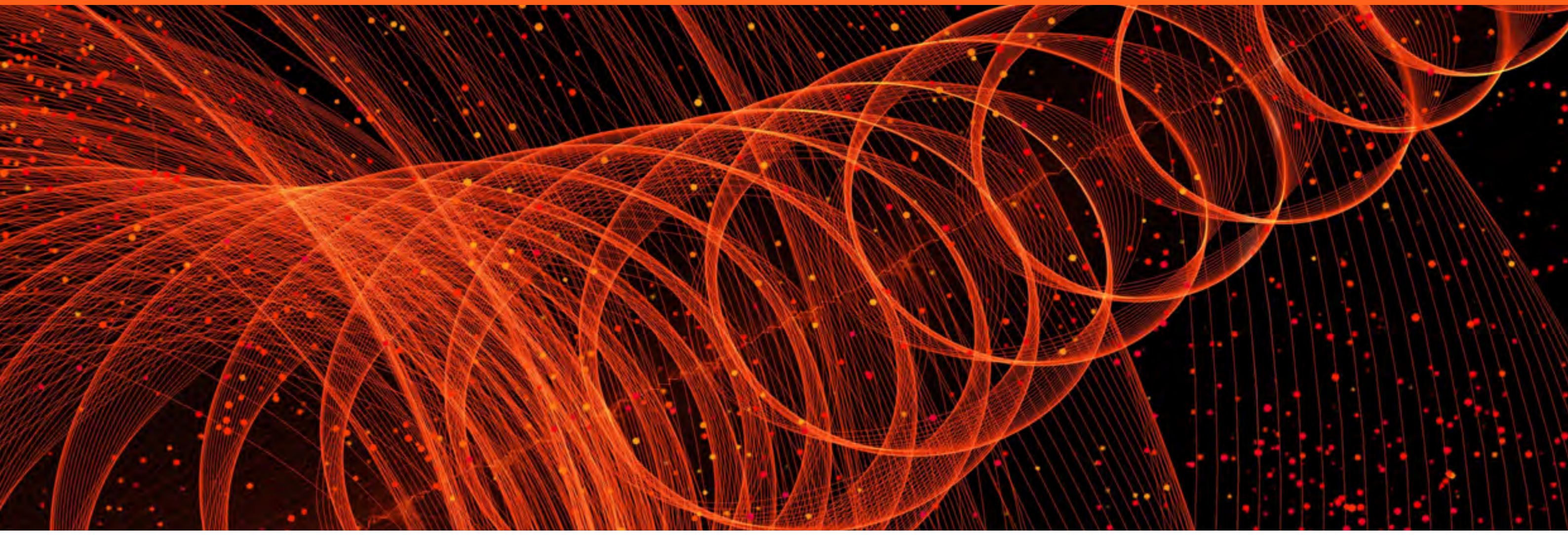
- i is the square root of -1
- $\hbar$ is the reduced planck's constant (equal to h/2π, where h = 6.63*10^-34)
- ψ is the wave function of the particle
- H is the Hamiltonian Operator (corresponding to the energy of the system)

Now, the salient part of this equation is the wave function. This is the part of the equation that describes all the characteristics of a particle. According to the Born Rule (postulated by Max Born) the square of the modulus of the wave function, given by Ψ2 , is proportional to the probability density of the particle, that is, the probability per unit volume of the concerned particle being there at the time. This is because the wave function itself returns complex numbers, which could not represent real quantities. Thus, a wave function can be graphed, and the amplitude of the wave at any given point squared gives the probability density. Given its probabilistic nature, a normalized wave function fulfils:

$$\sum_{i=1}^{\infty} \psi_i^{2} = 1$$

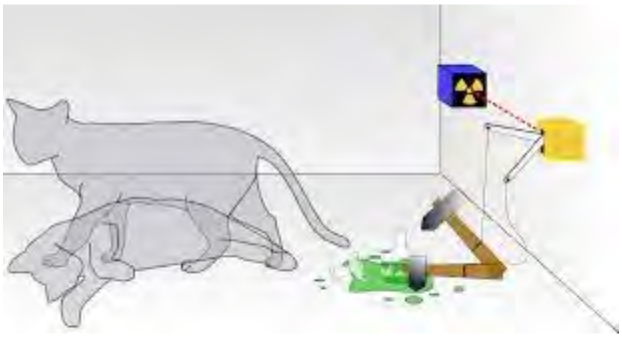
This means that the probability density across all locations is 100% - the particle has to exist somewhere.

However, the Schrödinger equation is not perfect, nor the quantum theory itself, by any means. One of the biggest questions is that posed by the measurement problem. The



measurement problem is how or if wave function collapse occurs after a measurement is taken.

Suppose we have a particle in a box. For analogy's sake let us say the wave function tells us the particle is equally likely to be in the four corners of the box, everywhere else having a negligible probability of it being there at the time. Now, we shall open the box, and, hypothetically, determine the location of the particle. What would the wave function be now? We know with 100% certainty where the particle is, so the probability density is 1 in this location, and 0 everywhere else. So it is clear that the wave function has changed. Initially it was a combination of multiple states of different locations (called a superposition) and now it is only one state of one location. It has changed from a wave-state of probabilities to a localized particle.

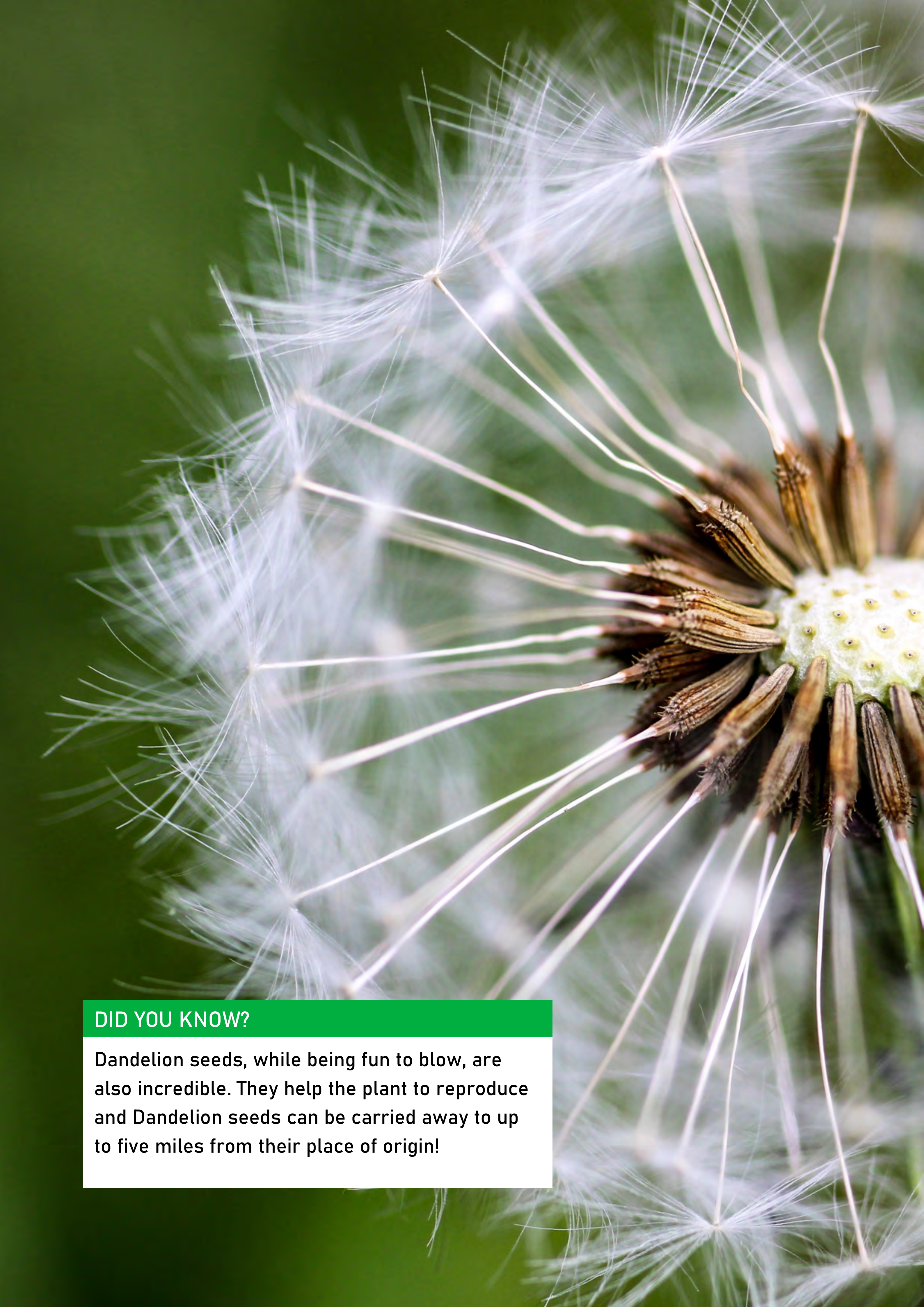


But here lies the problem: The Schrödinger equation does not tell us to change the wave function. There is no mathematical reason to do so. For some reason, a quantum state interacting with an external environment (an observation) results in the whole system collapsing.

Let us use one more analogy – this time a little more famous. Suppose you have a box containing a radioactive atom that decays once every hour and a Geiger–Müller tube connected to a glass phial filled with poison gas. Inside this box we shall also place a live cat. Of course we are discussing Schrödinger's cat. After 30 minutes is up, there is a 50% chance the atom's nucleus has decayed, which would result in the GM tube detecting this and the gas being released, killing the cat. We can say that the cat is 'entangled' with the quantum state (the atom). The cat is thus 50% dead and 50% alive. Once the box is opened, we can confirm the cat's status as either dead or alive – not both. So how did the superposition of probabilities suddenly become one definitive outcome? After all, all we did was open the box. We did not interfere with the cat or the atom in any way.

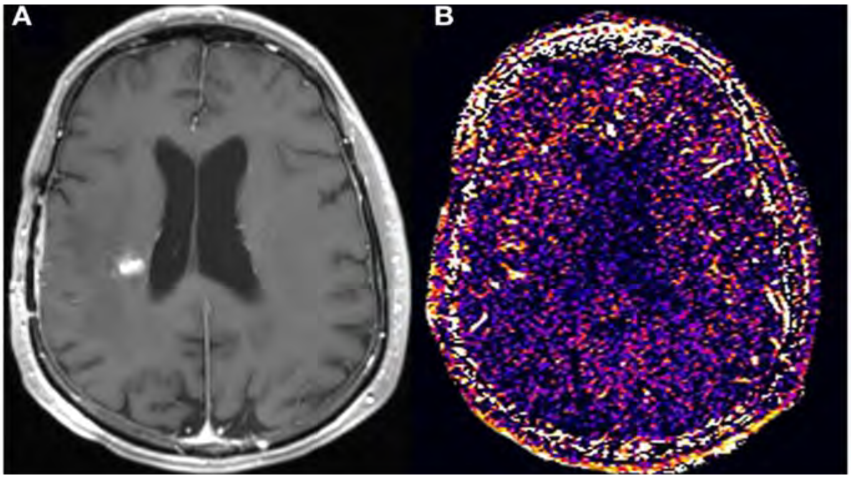
The measurement problem has puzzled physicists for decades. Of course, there have been several propositions and interpretations to try and produce an explanation, such as quantum decoherence, spontaneous wave collapse and even parallel universes. However, none of them have definitively resolved the issue, some being quite far off. It seems almost that the quantum theory itself is not wholly complete. But, with ever-accelerating research in the field, perhaps one day we will finally solve the infamous quantum measurement problem.

Edited by Youyou Yu



DID YOU KNOW?

Dandelion seeds, while being fun to blow, are also incredible. They help the plant to reproduce and Dandelion seeds can be carried away to up to five miles from their place of origin!



What are Glioblastomas and how effective are Oscillating Field Therapy in treatment?

Can Oscillating Magnetic Field Therapy be used to cure Glioblastomas or is more research required?

By Jathumilan Sasikumar (Y13)

Overview:

Glioblastomas, which can otherwise be referred to as a grade IV astrocytoma or glioblastoma multiforme (GBM), are the most common type of cancer in the brain and the most aggressive due to their malignant properties. Despite countless years of research and technical advancements, the outlook is still appalling with the average survival rate of patients with GBM being only nine to twelve months. [1]

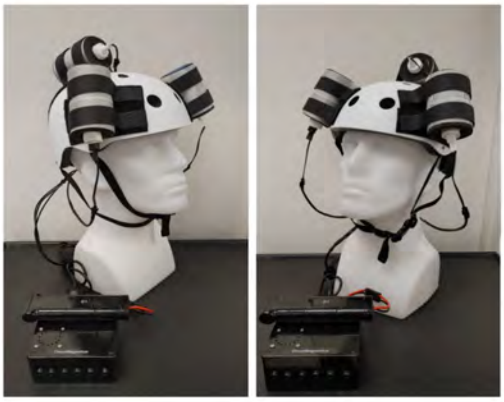
Causes:

A GBM is created when a brain cell called an astrocyte, which helps to support and nourish neurones as well as synthesise fibrous tissues in response to injuries in order to aid the restoration of brain damage, divides uncontrollably forming a tumour. [2] Usually, this occurs due to the genes that regulate cell division being damaged through exposure to mutagens such as radiation and carcinogenic chemicals. Additionally, this process can also occur naturally as mutations aggregate due to errors in DNA replication such as substitutions or deletions. The result is an astrocyte cell that performs uncontrolled cell division and will form a malignant tumour that invades the grey matter surrounding it as well as other organs through metastasis (when cancer cells break off a tumour and spread to other parts of the body through the bloodstream or lymphatic system), which is devastating to the human body. An example of a genetic condition that can cause GBM formation is Li-Fraumeni Syndrome (LFS) which is caused by mutations in the TP53 gene and is inherited in an autosomal dominant manner. TP53 is a tumour suppressor gene meaning that it encodes for a protein that repairs DNA in order to prevent mutated DNA from being inherited by daughter cells in mitosis. If the DNA contains too many mutations for it to be effectively repaired, TP53 proteins signal these cells to undergo apoptosis (programmed cell death).[3] Although most tumour suppressors are inactivated by frameshift or nonsense mutations, most TP53 mutations are actually missense and therefore cause single amino acid changes at many different locations depending on the position of the mutation. [4] Mutations in the TP53 gene will result in a different sequence of amino acids being joined together by peptide bonds at a ribosome. Since the order of residual groups (on the polypeptide chain) is now different, the protein formed will have a different arrangement of hydrogen bonds, ionic bonds and disulphide bridges, etc. The secondary, tertiary, and quaternary structures of the p53 protein may now be different so it is possible that this protein has an altered 3D shape. Ultimately, the altered shape of the TP53 protein makes it less capable of repairing mutated DNA, and therefore, mutated DNA within astrocytes is more likely to be passed down to daughter cells, increasing the likelihood of a cancerous astrocyte cell being formed. A single cancerous astrocyte is all that is needed for a deadly GBM to invade the brain or spinal cord. However, LFS is certainly not the only cause of glioblastomas; other triggers include genetic disorders such as neurofibromatosis, tuberous sclerosis, Turcot syndrome or environmental factors such as exposure to smoking, pesticides and even viruses including SV40(common in HIV patients) or cytomegalovirus (mainly affects babies). [5] [6] [7]

Clinical presentation and diagnosis:

Normally, a GBM will remain in an asymptomatic state until it grows to a size where it begins to invade brain tissues and increase intracranial pressure which can reduce blood flow to specific segments of the brain or make them ischemic (without blood flow) altogether. As a result, patients with GBM will usually present with headaches, nausea/vomiting (which can be caused by damage to medulla oblongata), confusion/ decline in brain function, memory loss, or seizures (primarily in people with no history of seizures).[8] In 25% of patients, a seizure is a presenting symptom and the chance of a seizure occurring at a later stage of the disease is 50%. [9] Patients who are presenting with the above symptoms will have to undergo initial diagnostic testing which will usually involve a computed tomography (CT) or magnetic resonance imaging (MRI) scan. On an MRI scan where the tumour is enhanced with gadolinium contrast to improve the clarity of the image, most GBMs will appear as an irregular mass with ring-enhancing lesions which are areas of damaged tissue where the borders are much brighter than the rest of the lesion when viewed with an MRI. [10] Additionally, necrosis (death of body tissue) is an integral feature of a GBM and it is required for a brain tumour to be classified as a GBM on the World Health Organization classification system. [11] However, since other lesions such as abscesses or multiple sclerosis can have a similar appearance, a stereotactic biopsy or craniotomy is required in order for the diagnosis of a possible glioblastoma to be definitive. [12] A stereotactic biopsy involves imaging (usually x-ray) in at least two planes to create a three-dimensional image of the lesion on a computer. A neurosurgeon will then examine the image to select the appropriate coordinates for the journey that the biopsy needle will take to the lesion. The biopsy needle is inserted into the head and through the skull, allowing a small piece of cancerous tissue to be removed during the procedure which can be analysed by a pathologist for an official diagnosis. [13] On the other hand, a craniotomy is a much more invasive procedure that begins with an MRI scan to provide an image of the brain which the neurosurgeon examines to plan the exact location of bone removal and the angle at which they need to operate in order to access the lesion. The bone flap is removed almost completely and with a cranial drill a sample

A Figure 1



B Figure 2

of the lesion is obtained. The bone flap is then replaced with titanium plates and screws, and the sample is analysed by a pathologist similar to a stereotactic biopsy[14]. It is imperative that the pathologist can distinguish between a primary or secondary glioblastoma as primary GBMs have a worse prognosis and different tumour biology meaning that their response to therapy is different to that of a secondary GBM. Consequently, a distinct course of treatment and therapy needs to be chosen[15].

Treatment:

The efficacy of minimally invasive oscillating magnetic field therapy on treating glioblastomas: One possible method of treating GBMs is through the use of oscillating magnetic field (OMF) therapy. Over the previous decades, there has been a multitude of studies indicating that electromagnetic field exposure can cause apoptosis and DNA strand breaks which is when the DNA double helix fragments within a cell, usually creating a cancerous or biologically inactive cell as a result. This is because a strong electromagnetic field interferes with the phosphodiester and hydrogen bonds that help maintain the DNA's structure as well as exert forces on charged ions which will interrupt the diffusion of ions down an electrochemical gradient through phospholipid membranes. These harmful properties of electromagnetic fields can be harnessed to treat diseases such as cancer. [16] For example, in vitro as well as in mice and other rodents, non-ionising electromagnetic fields have shown anti-tumour effects and in 2021, four American neurosurgical experts conducted a study on an onco -magnetic device which showed very promising results that indicate that OMF therapy could eradicate the need for surgical resection and chemotherapy to treat GBMs. [17] According to the researchers, "The Oncomagnetic device consists of three oncoscillators securely attached to an acrylonitrile butadiene styrene helmet and connected to a microprocessor-based electronic controller operated by a rechargeable battery" and can be observed in Fig. 1. The device causes caspase-dependent apoptosis of cancer cells by increasing the permeability of the mitochondrial membrane permeability transition pore which releases apoptotic factors into the cytoplasm when there is abnormally large calcium ion transport which is triggered by OMF therapy[18].

The study was conducted on a 53-year-old male (who can be seen in Fig. 2 wearing the oncomagnetic device) who had previously undergone a left frontal craniotomy in 2018 when a GBM was removed but he was now experiencing a rapid recurrence of the tumour despite both radiation therapy and taking temozolomide which is a common chemotherapy drug for malignant gliomas. Since all treatments for his condition had been exhausted, he was enrolled in the Expanded Access Program (EAP) which permitted treatment using OMF therapy in an endeavour to save his life and experiment on the effects of OMF therapy on

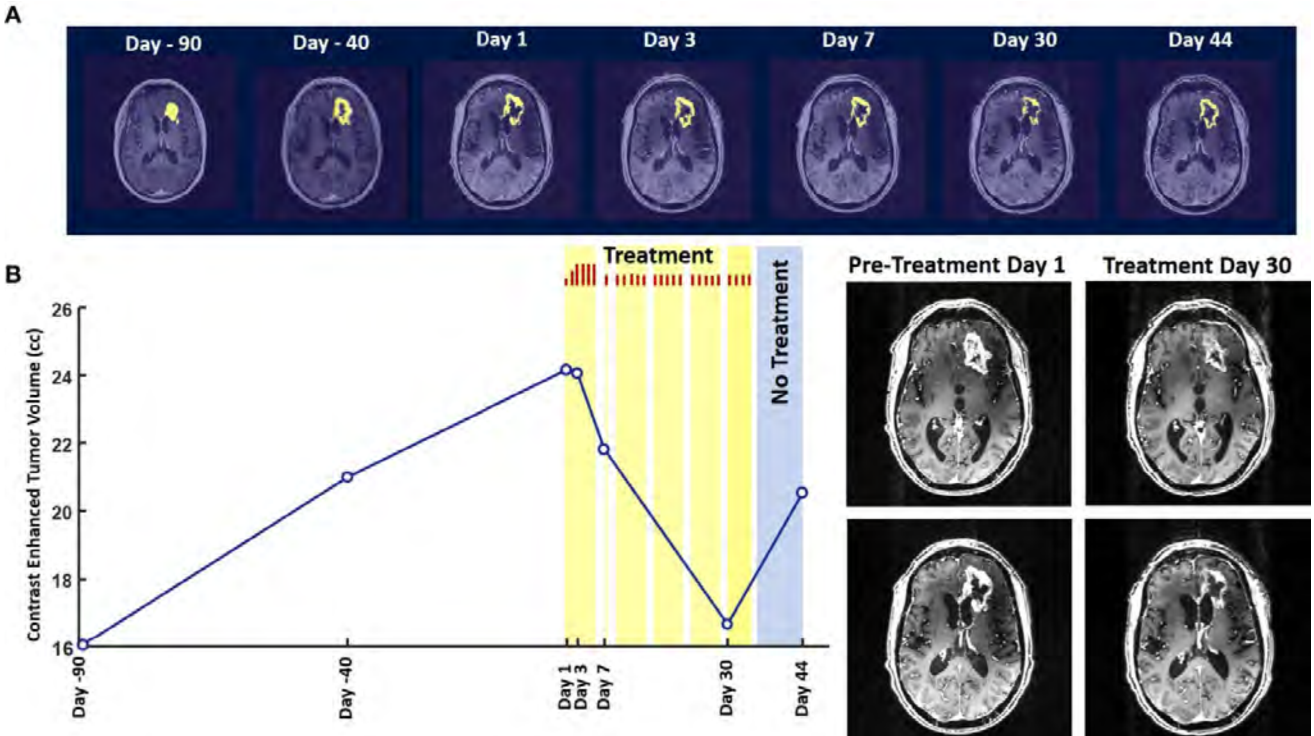


Figure 3 and 4

cancer cells within a human brain. All other courses of treatment were stopped and the OMF therapy began in the Peak Center clinic for the initial three days to familiarise the patient and his spouse with the operation of the device and to also monitor the patient to observe any early signs of any undesired effects. The treatment lasted two hours on the first day but was progressively increased to two and three 2-hour sessions with one hour breaks. After the first three days, the patient was allowed to continue with the treatment at home and his spouse was to keep a daily log where she would record how long the treatment lasted each day as well as signs of progression and side effects. The daily length of the treatment was changed multiple times due to complaints from the patient regarding the length of the sessions and was initially reduced to two hours/day with the weekends off but this was incrementally increased to three hours/day as the patient felt more comfortable with the treatment. The Principal Investigator of this study and the treating clinician implemented weekly check-ups with the patient in order to take MRI scans and the relevant blood tests to ensure that the patient was safe and to evaluate whether the tumour was shrinking. Unfortunately, the study ended prematurely at only 36 days since the patient reported headaches from Day-30 for which he was given the appropriate blood pressure medication, and on Day-36 he suffered a closed head injury from a fall. The last check-up occurred on Day-44 and the patient was then admitted to the hospital as a result of the head injury; the evaluation phase of the study was commenced. It is important to note before discussing the findings and conclusion reached by the researchers that three of the four researchers were listed as inventors on a US patent application for this oncomagnetic device used in the study. As a result, it is plausible that the researchers may be biased in favour of their device and therefore may have skewed data or omitted evidence of side effects from the study to make the device seem more effective than it actually is. This would be beneficial for them as it would allow the oncomagnetic device to be introduced to the US healthcare market more quickly which would certainly be very lucrative for them. The fourth researcher who was not an inventor declares that "the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest", however, it is difficult to verify the truthfulness of this statement and I would therefore advise readers to be wary of the conclusion reached by the study.

In Fig. 3, we can see MRI scans taken using a Siemens Magnetom Terra 7T scanner which suggests that as the days after starting treatment increases, the volume of the GBM decreases until treatment is stopped on Day-36 and then the tumour begins to increase in volume again to approximately the same volume as the start by Day-90. Fig. 4 models this variation in the GBM'S volume more clearly and we can see that there is a decrease in the tumour's volume of approx. 10% in the first week and there is a total decrease in tumour volume of approx. 31% by day 30. To put this into context, Optune therapy which is one of the most effective GBM therapies internationally, only displays an approx. 15% reduction after three months which indicates that OMF therapy is approximately six times more effective than one of the leading therapies currently available for GBM reduction. [19] Using the MRI scans and various tests, the researchers calculated that when the treatment length was six hours/day, there was a tumour volume reduction of 2.32cm^3 /day and when it was two or three hours/day, the volume reduction was 1.03cm^3/day. [20] Assuming that glioblastomas can grow 1.4 % a day and that the average GBM patient can only tolerate two or three hours of oscillating magnetic field therapy per day (like the 53-year-old man in this study) - meaning that the tumour reduction volume is 1.03cm^3/ day, This oncomagnetic device should be capable of entirely eradicating tumours that are smaller than 73.6cm^3. [20] This is very impressive if you consider the fact that the average size for GBMs is 19.17± 14.29 cm^3 [21].

Sadly, the patient in the study died as a result of the closed head injury sustained from his fall on Day 36. Three months later but the data seems to suggest that the GBM could have been completely destroyed if he had undergone the therapy for a year so he would have been able to live a normal lifespan provided that the GBM did not recur. The researchers claim that the fall and headaches experienced by the patient were unrelated to the therapy and that he was experiencing these symptoms before treatment had begun. They also claim that the patient suffered no adverse effects from what they discovered from MRI scans and other tests which is supported by the patient's spouse who reported that the patient experienced "improvement in speech and cognitive function" but this is subjective since she may have pre-empted for him to recover with time. Additionally, since this study was conducted on a single individual and was ended prematurely, no meaningful statistical test could be applied to the findings and it is impossible to decisively conclude whether the therapy is as effective as the researchers suggest it is.

Therefore, I conclude that oscillating magnetic field therapy so far seems to be an effective method for treating GBMs as shown by tumour volume reduction statistics however more studies will need to be conducted (ideally with larger sample sizes so that anomalies can be identified) to fully explore how effective the therapy is at GBM reduction, whether it has side effects, and to confirm that the researchers of this study are giving an unbiased view on the efficacy of oscillating magnetic field therapy. I strongly believe that if the researchers are giving an accurate and reliable report on the ability of their oncomagnetic device, we may have the future of oncological treatment in our hands.

Edited by Agustya Iyer

The Future of Lab Grown Organs in Medicine

By Chirag Vinod (Y13)

With the huge advancements in medicine and technology over the last 50 years, many new and previously impossible treatments have been made available to patients with problems relating to their organs such as kidney failure. However, there is still a huge shortage of suitable donor organs, acting as the most significant single limiting factor in transplant programmes.[1] A solution to this problem would be to artificially grow organs in laboratories such that these engineered tissues would integrate into the host's body naturally as well as be able to regenerate and repair itself. The field of study that focusses on such advancements is tissue engineering which is an interdisciplinary field that combines cell biology, biomaterial synthesis, and engineering techniques to generate biological tissue replacements for transplants and tissue culture applications.[2] Much research has been conducted in this field and there have been three main components identified which are vital for its success in relation to regenerative medicine. These are engineering cells, engineering materials and engineering tissue architecture [3], which are often referred to as the three pillars of tissue engineering. For organs to be grown effectively in labs, all three of these aspects must be present and perfected. However, at the current moment, these three pillars have not been integrated together efficiently and has meant that any tissue engineered has been on a lower scale.

The first pillar, engineering cells, refers to the sourcing of the fundamental building blocks of the tissue – the cells. These cells must be able to differentiate into the necessary cell types found in the target organ and be able to replicate and repair the tissue.

Figure 1 a simple representation of the three pillars of tissue engineering[11]

One such source of cells is mesenchymal stem cells (MSCs). These are cells which are isolated from a variety of tissue such as umbilical cord, menses blood, bone marrow, adipose tissue, etc and have multipotent properties to differentiate into a variety of cell types including bone, fat, muscle, neuron, islet cells, and liver cells under specific in vitro conditions such as the presence of specific growth factors[4]. The advantage to the use of MSCs is that they can be extracted from adult tissues, meaning there are no ethical reasons against the use of MSCs unlike the use of other stem cells such as embryonic stem cells (ESCs), which are extracted from the

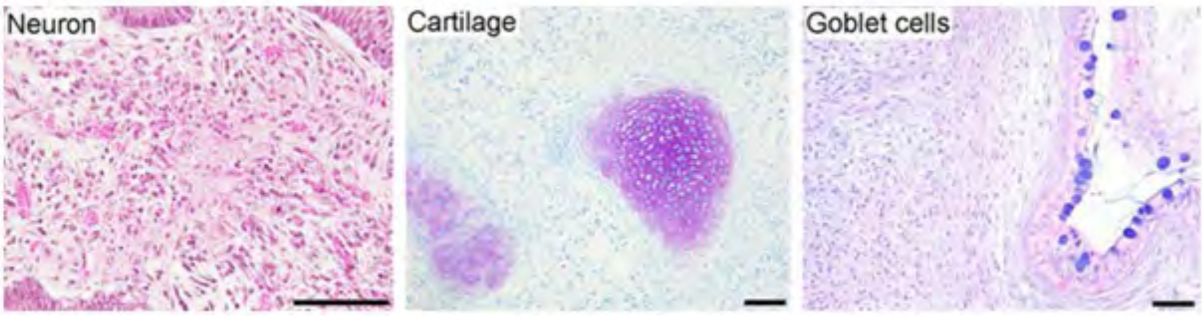


Figure 2 three germ line cells/tissues differentiated from iPSCs: neurons, cartilage, and goblet cells in the intestine[12] inner cell mass of a blastocyst. Unfortunately, MSCs do not have the capability to differentiate into all types of specialised cells and their differentiative capacity is donor-age dependent [5], meaning their uses are limited. A relatively new alternative to MSCs are induced pluripotent stem cells (iPSCs). These are differentiated adult stem cells that have been reprogrammed into an embryonic-like state by the introduction of four growth factors in embryonic stem cell culture conditions.[6] Therefore, iPSCs are not limited in the cell types they can differentiate into as they are essentially in a state like that of ESCs. The discovery that mature, terminally differentiated cells can be converted to pluripotent stem cells earned Shinya Yamanaka and John Gurdon the Nobel Prize for Physiology or Medicine in 2012. Unfortunately, certain studies on mice have shown that iPSCs are prone to developing tumorigenesis, where the transplanted cells gain malignant properties similar to that of cancer cells.[7]

The second pillar, tissue architecture, is about the scaffolding necessary for a new organ to be made from the procured cells. This is because cells will not naturally integrate themselves into tissues when transplanted without a suitable structure to support it. Hence, a scaffold must be used and created in the lab. This scaffold will act as a guide for the growth of new organs and will allow the cells to adhere to one another.[8] It will also promote growth of the implanted cells. The scaffold must be biocompatible to minimise the immune response of the host body and it must be highly porous so cells can enter the scaffold with ease and attach to it. A large surface area to volume ratio is also a requirement as the rate of exchange of vital substances must be kept high for the organ to function. As the cells multiply and the organ grows, the scaffold is slowly depleted such that at the end of the process, the scaffold is completely replaced by a new fully functioning organ in vivo. This means that the scaffold must also be biodegradable to help with this process. Most scaffolds consist of a mixture of polymers, bio-ceramics and hybrid materials.[9] The source of these materials have their separate benefits with natural polymers such as fibrin and collagen having better biological compatibility and man-made polymers such as polypropylene fumarate having an improved rate of cell attachment and the ability to be manipulated into complex shapes.

The final pillar, engineering materials, relates to the technology necessary to create these scaffolds and organs. One such example is stereolithography in which a 3D object can be made in a layer-by-layer fashion using a computer-controlled laser beam. This therefore allows structural parameters such as porosity, and gradients to be controlled.[10] This technology was used to print an intricate system of blood vessels surrounding an air sac - a mini lung. The tests showed that the blood vessel was sturdy enough to prevent the rupturing of the vessel as blood flowed through it and that the rate of oxygen uptake by red blood cells was similar to that in the lung's alveoli.

In conclusion, we are currently at the cutting edge of tissue engineering and if all components of regenerative medicine are integrated efficiently, it will be possible to grow organs in labs in the near future. This is a field of medicine that is being worked on to this day but the main barriers are the conditions required in the lab in order for the cells to grow effectively on to the scaffold and into an organ. Scaling up the work is also an issue at the moment as larger organs need more complex internal structures with greater capillaries, which are smaller than the human hair.

Edited by Daniyaal Khizer

Giruses: The organisms that shouldn't exist

By Poorwa Gunarathna (Y11)

The Girus is essentially the abbreviated form to refer to the classification of the giant virus. This species should simply not exist, going against everything humans previously knew about the nature of a virus. And here's why.[1]

First let us consider the concept of a virus. A virus is actually so unsophisticated that it is considered on the "edge of life": it has a special taxonomic position, in that they are not plants, protists, animals, or prokaryotic bacteria (single-cell organisms without defined nuclei), and are generally placed in their own kingdom. The function of a virus is simple and ruthless: to hijack a living organism and to use its cellular organelles to multiply.

There is a prevalent argument as to if a virus is living or dead. Many have settled on the in-between, but many have argued that it is not the virus that is living but rather the infected cell, also known as the Virocell, which contains viral particles that can be viewed as seeds or spores. Many others simply think that viruses are the makeup of dead material: the product of genetic material enclosed in a capsid and are arguably not actually alive. However, for an organism that requires victims to multiply, it must have evolved from something. Perhaps it could be the evolution of escaped genetic material from an organism, or the result of a mutation in a very simple prokaryotic bacterium.[2]

Very recently, viruses have become even more of a mystery, where scientists have discovered the presence of giant viruses (Giruses). These are organisms that break the laws of everything we know about the nature of viruses. It is even more shocking that they have their own parasite: the Virophages. This is similar to the concept of Bacteriophages, that hunt bacteria. Since the discovery of the girus in 2003, they appear to have existed everywhere: in the ocean, in the mouths of humans and even in the intestine of a pig.[1] [2]

Relative to a regular virus such as the Coronavirus (measuring at 100 nm) or the Poliovirus (which measures at 30nm), giruses such as the Mamavirus have been found to be a huge 600 nm in diameter, which, really, explains why they have been hidden for so long: we just haven't been looking.

Giruses generally look for amoeba and other single-celled organisms as their victims, attaching onto the surface proteins and using their natural processes to enter the cell. Their goal after infiltrating the cell is to "misappropriate the victim's infrastructure and procreate," like all viruses. However, the girus will then rearrange the cell's infrastructure and form a super factory called a viroplasm that uses protein-production organelles, ribosomes and mitochondria- for energy- to assemble multiple new Giruses. [1]

These giruses are contrary to regular viruses, in that they use more sophisticated approaches, such as forming a membrane around the viroplasm in order to shield it from the cell's antiviral defenses. The girus then induces self-destruction of the cell, releasing more giruses to find more prey. [2]

What makes a girus even more special is not their size or "modus operandi" [1] but the complexity of the Giral structure. Girus genes are largely in contrast to those of a regular virus, which are thought to contain the simplest of instructions to infiltrate and procreate. Instead, Girus genes are completely unique, where some sections of the genome even contain information to run sophisticated processes such as nutrient intake regulation, energy production, light harvesting, replication and basic cellular functions to allow the cell to operate. In addition to this, scientists have researched Giruses that have such complex genomes that they are able to maintain a basic level of metabolism on their own; if this is true, this changes everything we know about viruses. Giruses may even insert their genome into those of hosts to produce chimeric organisms. This could signify that they have an unseen influence on evolution, by changing genomes to help them survive. [1]

As briefly previously mentioned, giruses have their own microorganism that specifically targets them: the Virophage. For example, the Virophage Sputnik 2 hunts the Girus: Mimivirus,[4] which itself is hunting an Amoeba, for example: Acanthamoeba polyphagia. Sputnik 2 [3] is extremely simple and minimalistic, with only the ability to hijack the viroplasms of the Mimivirus, as it is unable to replicate itself. Once the Mimivirus infects the amoeba, the virophage is very subtle on how it operates, by integrating its DNA into the newly produced Giruses, like "sleeper agents." [1] once any of these.

When giruses hijack another host successfully, the effects of the DNA integration become clear when it is mostly Sputnik 2 virophages that are produced, not Mimiviruses. However, Giruses also have defense systems. Like bacteria that have the CRISPR gene, Mimiviruses have a defense system named MIMIVIRE, standing for Mimivirus Virophage Resistance Element, [1] similar to an immune system. In turn, protists that are likely to be infected have been found to integrate virophage DNA into their genome in order to produce virophages, and not Giruses, when they self-destruct. This helps the survival of their species. [3]

And there it is, the giants of the "micro-universe" that exists everywhere: an invisible battle that constantly rages on in a competition for food, space and resources, no matter what the cost.

Edited by Daniyaal Khizer

Everyday Elements

By Ashutosh Chauhan (Y11)

Elements have been everywhere around us for a long time, and Dmitri Mendeleev eventually consolidated and organised these into the Period Table we know today for the scientific community and the human world alike. In 7000 BC Africa, lead smelting began, and this is the second oldest element found by humans. Back then, lead was a huge part of human lives. Let us look at some elements used in our lives, but we are likely unaware of.

Figure 1 - A standard thermometer

To start with, the Group 7 halogen chlorine is used in water treatment as well as in disinfectants, due to its oxidising nature. It can easily penetrate pathogens and destroy the intracellular enzymes and proteins to make them non-functional, eventually killing the pathogens. Do you ever wonder why there is always a sharp odour near a swimming pool? That's chlorine!

Some elements are also used to treat illnesses and diseases, and cobalt is just one example. The element is hard and magnetic, and its isotope cobalt-60 produces a stable megavoltage radiation beam in the form of gamma rays. This allows it to be effective in cancer treatment via radiotherapy.

William Ramsay's discovery of xenon in 1898 finds its application in high-speed photography and is typically used in lamps that produce extremely short and intense flashes of light. But why is xenon used here? Well, xenon is a group 0 element, also known as a noble gas. Noble gases are highly stable elements due to their filled outer shell electronic configuration. Xenon also has a high boiling point due to strong intermolecular forces between the atoms which means more energy is required to break these bonds. This makes it attractive for high-speed photography where it copes well with high temperatures generated during this application.

Next, when a tooth (decay is serious) and is beyond the 'drill and fill' treatment often practised in dentistry, palladium alloys come into play. Palladium is used for the manufacture of crown and bridge restorations (which is used to reconstruct the tooth structure) constructed by dental technicians. The transition metal palladium is utilised because it is a non-corroding hard metal that remains unaffected by oxygen and other elements.

Another transition metal called tungsten is used widely. Tungsten is a dense metal with the highest melting point of all metals, so is used as a filament in incandescent bulbs. Tungsten serves well as a filament owing to its high conductivity because it possesses free delocalised electrons that can carry an electric current. Furthermore, the metal is used in steel to impart strength. Tungsten's high melting point is simply due to the strong force of attraction between the metal cations and the sea of delocalised electrons in this metal.

Did you know that your six-inch mobile phone contains gold in it? The transition metal is used for the wiring of electronic chips inside your mobile phones. This is because it can conduct electricity due to it having delocalised electrons which can carry an electric current. Also, it is malleable and ductile as the layers of metal atoms can slide over each other without disrupting the metallic bonding. These properties allow it to conduct signals very effectively across the incredibly thin chip wiring.

If you have a fever, usually you would use a thermometer (Figure 1) to measure your body temperature. Do you know what that shiny liquid filled within it is? The answer is mercury. Mercury is the only transition metal that is in a liquid state at room temperature. Not only is it used in thermometers, but also in making barometers, electrical switches, sphygmomanometers and other instruments.

To conclude, the elements on the periodic table are everywhere and used frequently in our daily lives in a variety of fascinating engineering applications. For example, if gold had not been discovered, the conductivity and strength of signals on our phones would not be strong. If mercury, had not been found, we would not be able to know our body temperature. How helpful have cobalt and palladium been on the health front? Had tungsten not been discovered, we would still be living with oil lamps. In conclusion, the elements listed in the periodic table are vital parts of all of our day-to-day lives—far more than we may recognise.

Edited by Daniyaal Khizer

Stem Cell Research

By Daniel Han (Y12)

As a modern type of regenerative medical treatment, it is undeniable that stem cells hold huge potential. To be able to take an undifferentiated embryonic stem cell and manipulate in such a way that any type of specialised cell could be produced — this would completely revolutionise the healthcare industry. People would no longer have to wait for months for organ transplants. Hundreds upon thousands of lives could be saved. It is with that goal that researchers dedicate themselves to discovering a way to carry this out.

Since the latter half of the 20th century, stem cells have been greatly researched by a range of scientists. It was kickstarted due to the findings by Canadian biologists Ernest McCulloch, James Till and Andrew J. Becker at the University of Toronto.[1] A particularly noteworthy discovery was in 2007, when a Japanese team led by Shinya Yamanaka found a way to make induced pluripotent stem cells (iPSCs) from human skin cells.[2]

What are stem cells?

Stem cells come in two main forms — embryonic and adult.

Embryonic stem cells can be found in the embryo when they are about three to five days old. These cells are able to differentiate (transform, if you will) into any type of specialised cell, which is amazing, however, there is strong opposition in researching these cells. To experiment on embryonic stem cells, the embryo is destroyed while harvesting the cells. Many believe that an embryo is already a living human being and so it should have equal rights to any other human.[3]

Adult stem cells can be found in essentially all age groups. They are found in areas of the body such as the bone marrow, the blood and the skin. These cells are unable to differentiate into any specialised cell, however, they can still be used to repair damaged tissue in the same area that they are found in.[3]

Mentioned above, induced pluripotent stem cells (iPSCS) are a slight variant of embryonic stem cells. iPSCs are made from adult stem cells, 'de-differentiating'. iSPCs could potentially produce new cells for any organ or tissue. The biggest hurdle is to find a way in which they can be produced safely.[3] When that day comes, the healthcare industry will never have to worry about running out of organ donors.

What types of stem cell treatment are there?

Unfortunately, although a great deal of experimentation has been carried out, as of now, very few stem cell treatments have been proven to be absolutely safe and effective. The most common treatment would be the hematopoietic (blood) stem cell transplantation, which helps to treat some blood disorders by using cells from bone marrow. Even with this treatment, however, there is a chance that the patient's immune system might reject the stem cells and attack them — a case of graft versus host disease (GvHD). Symptoms of GvHD include things like diarrhoea, joint pain and even jaundice.[4] That isn't to say that you shouldn't undergo stem cell treatment — it is actually largely safe to take the treatment with success rates of up to 80%.[5] Nevertheless, it is important to consider the risks, no matter how minuscule they may seem.

What kinds of research have been carried out in recent years?

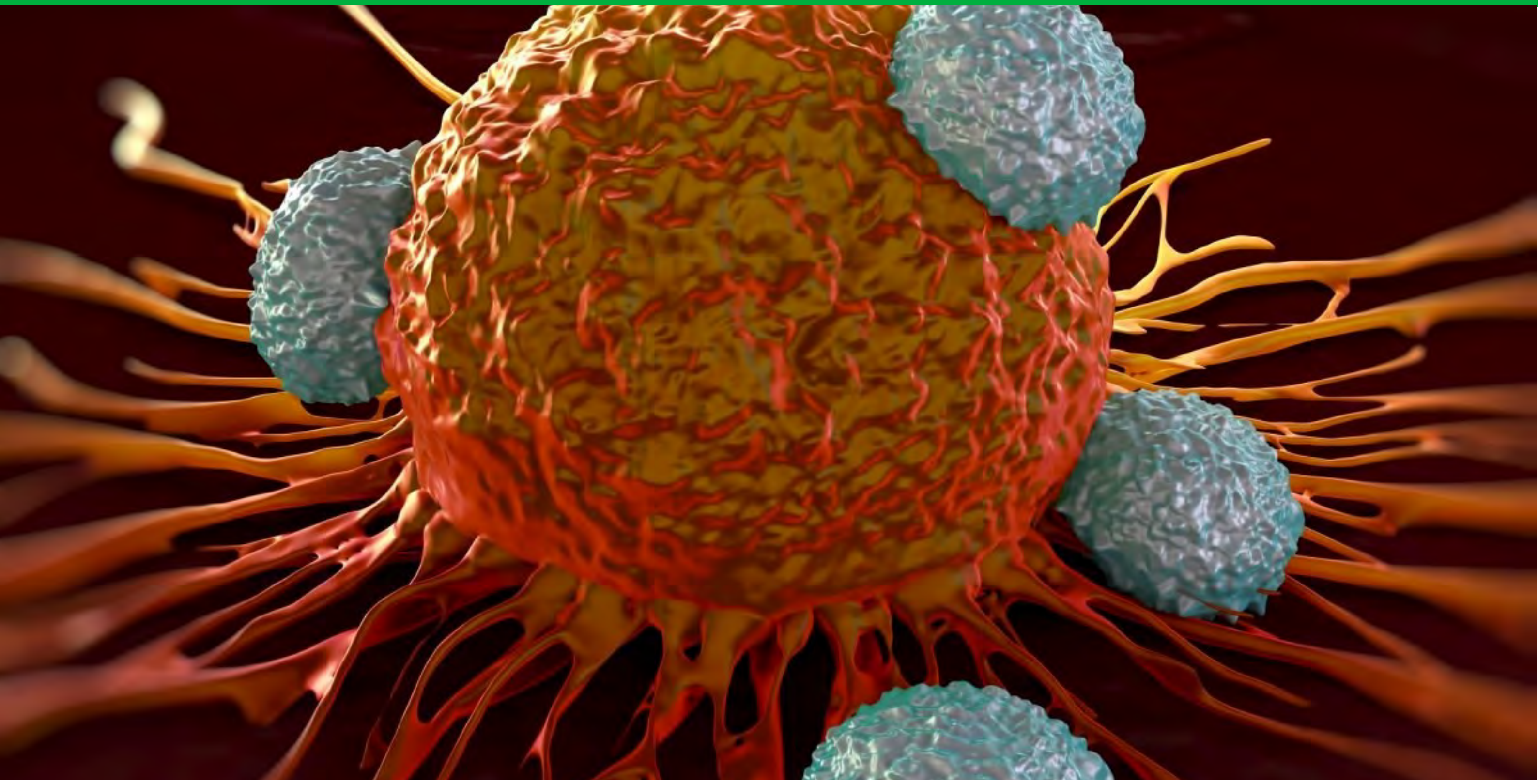
In recent years, there has been some very promising research into stem cells. One example is the research that the University of Cambridge is carrying out. After a decade of hard work, a team of researchers, led by Professor Magdalena Zernicka-Goetz, have managed to create model embryos from mouse stem cells.[6] These embryos have a brain and a beating heart, as well as the basis of the other organs of the body. What makes the embryos unique is that they were made from only stem cells — no sperm or egg cells were involved. This discovery holds lots of potential for the future of organ transplants and will no doubt bring about great changes to the healthcare industry too.

Another example is the recent developments in stem cell manufacturing. A research team led by biomedical engineer Professor Majid Warkiani made some new technology that could help with stem cell treatment. Working together with Australian biotechnology company Regeneus, researchers from the University of Technology, Sydney, have been able to develop a one-of-a-kind 3D printing system, able to harvest stem cells from bioreactors. This could potentially allow for wide-scale production of stem cells, offering Australia's health industry a surplus of these cells for patients that might need the treatment.

So, what's next?

Stem cell research is rapidly yielding results that hold great prospects. Scientists are working hard to find ways in which stem cells can be used safely and effectively. With researchers succeeding in making organs purely out of stem cells, it would seem that that day is coming ever closer.

Edited by Arnav Prasad



New Breakthroughs in Cancer Research

By Omar Mohubally (Y13)

What is Cancer?

Cancer is the second leading cause of the death globally, claiming approximately ten million lives per year. It is a condition where cells within different parts of the body grow and reproduce uncontrollably. The abnormal division of cancer cells can form tumours which can be benign or malignant. The main difference between the two is that benign tumours stay in their primary location while malignant tumours spread throughout the body through a process called metastasis. This is where the cancer can form the secondary tumours by invading neighbouring tissue usually by spreading through the blood or lymphatic system. The best way to treat cancer is to begin treatment early on as late stages of cancer are much harder to cure. The main three ways of fighting cancer in this modern age are through surgery which involves directly removing the cancer, chemotherapy which uses drugs to kill cancer and radiotherapy where radiation is used to kill cancer cells. In the same way cancer is constantly mutating and evolving, so is the treatment for cancer that is becoming more cutting-edge and developed year by year. These new 21st century treatments are highly promising and will bring us one step closer to ending the fight against cancer.

Can our immune system be used to fight cancer?

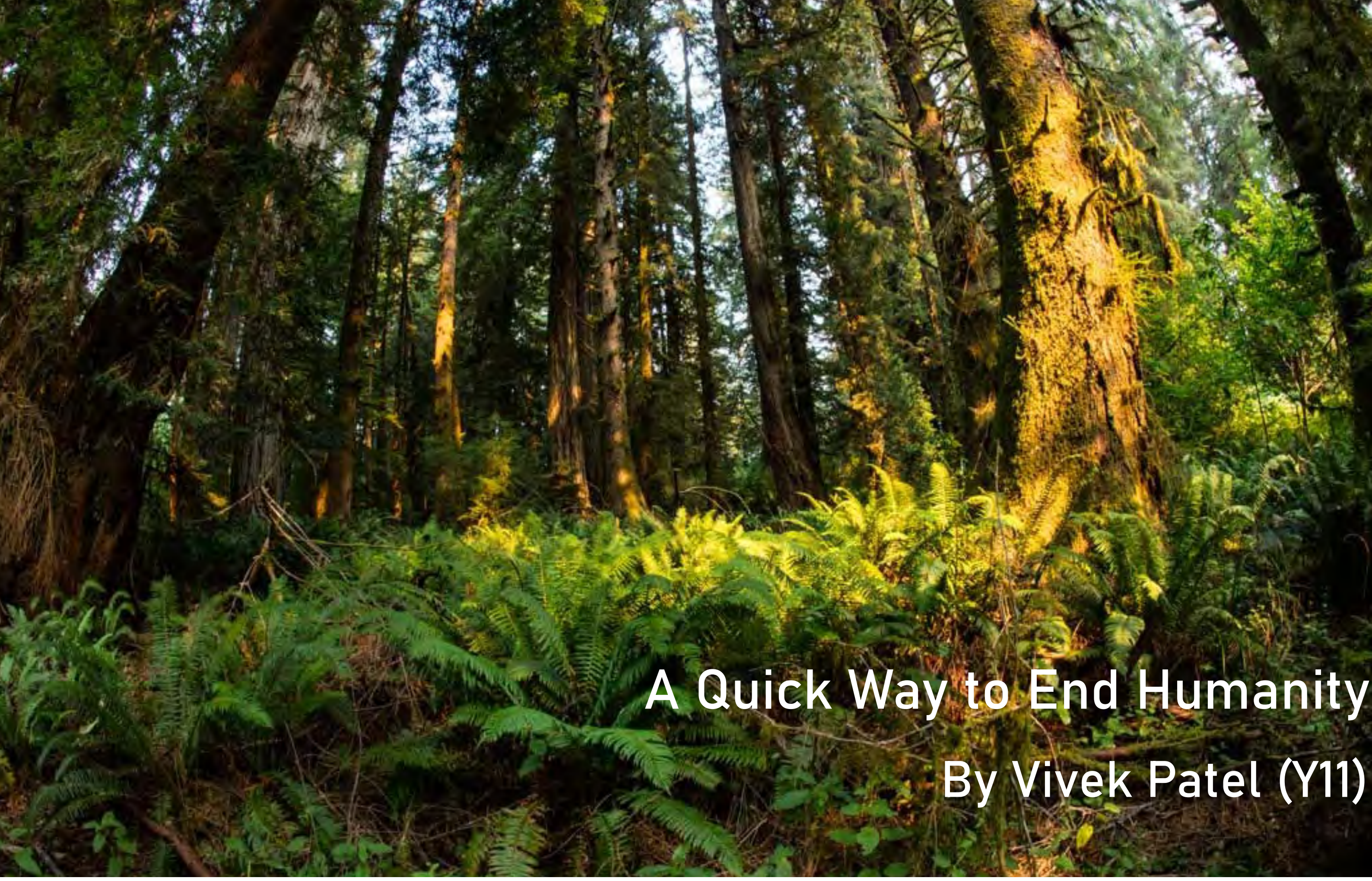
CAR T-cell therapy is a branch of immune-oncology which involves using one's own immune system to fight cancer. To understand it first you need to know how T cells work. They are a type of white blood cell which can have receptors on their surface. These receptors can latch onto protein fragments (called antigens) of cancer cells [1]. Next, the T cells inject toxins into cancer cells to kill them. However, cancer cells can disguise themselves as healthy cells in order to avoid being detected by the body's immune system so they can divide rapidly and grow to form a tumour. CAR -T cell therapy can be used to fight this by reprogramming T cells into CAR-T cells which according to Michel Sadelain (cofounder of Juno Therapeutics) “represents a radical departure from all forms of medicine in existence until now” [2]. First, a doctor will take a patient’s T cells out of their body by extracting a blood sample in a process called leukapheresis. Then an inactive, modified virus is used to introduce genetic information into a T cell. The T cells will then begin to produce special receptors which are called chimeric antigen receptors turning them into CAR T-cells. [3] These new CAR T cells are injected back into the patient’s blood and these modified receptors allow them to recognise the antigens of the patient’s specific cancer cell and attack the cancer cell in order to destroy it. Although CAR-T cell therapy has amazing potential there are some drawbacks. The side effects of Car T therapy can be quite severe. Typically, patients report symptoms including nausea, dizziness and loss of balance. In the more severe cases the therapy can cause neurotoxicity and cytokine release syndrome. However, these symptoms can be managed using medication and research is being used to minimise the side effects. Car T cell therapy clinical trials are being carried out in globally with other 500 clinical trials worldwide. The majority are being performed in East Asia (269 trials), followed by the US (225 trials), Europe with 62 trials [4]. These clinical trials have yielded significant results. For example, in the clinical trials remission rates of blood cancer has increased to 93% [5] in America.

Are nanobots the cure?

Traditional cancer treatments like chemotherapy can damage healthy tissue as the drugs target rapidly dividing cells which include cancer cells as well as healthy cells. Nanobots are a new medical breakthrough that allows cancer cells to be killed by drugs without the collateral damage by directing these tiny robots with magnets to cancer cells where they release chemotherapy drugs to kill the cancer cells. These robots are made by combining various biological structures like cells, proteins and DNA with chemical compounds like carbon nanotubes and magnetic (Fe_3O_4) nanoparticles [6]. These developments were 'biologists and materials scientists’ as described by Professor Bradley Nelson (Professor of Robotics and Intelligent Systems at ETH Zürich) [7] Magnetic forces are an integral part of helping the nanobots reach the cancerous areas of the body. They travel through the bloodstream with the aid of structures called micro rollers which were developed by scientists at the Max Planck Institute for Intelligent Systems [8]. These micro rollers are tiny magnetic spheres that roll against blood vessel walls. Their direction is controlled by magnetic fields which helps guide them to cancer cells. A team at Purdue University manoeuvred a biorobot using the same technique through the colons of a mouse and pig. Once they reach the tumour, they sense changes in pH levels as the fast metabolism of cancer cells produces a highly acidic microenvironment [9]. This change causes the nanobots to release their drugs in order to kill cancer cells. One of the challenges in this field of cancer treatment is getting the nanobots to reach the brain. This is because of the blood brain barrier, a natural filter that allows only some substances to reach the brain in order to keep pathogens out. However, Nelson did point out that ‘there is work using ultrasound to cross the blood brain barrier.

Overall, these new treatments have highlighted that there is a brighter future in the medical field. From rewiring our own immune system to fight the deadly disease to using microrobots to deliver drugs to cancerous cells there have been constant advancements as move towards the end goal which is finding a cure to cancer.

Edited by Agustya Iyer



A Quick Way to End Humanity

By Vivek Patel (Y11)

Biodiversity is the term that refers to the variety of living organisms in a given area. These include both organisms visible on a microscopic level (microorganisms) and organisms visible to the naked eye (plants and animals). Whether it be through facilitating pollination of plants, or preventing deadly climate change, or reducing the risk of a trophic cascade, each organism plays an important role in its ecosystem; so it is vital that they are permitted to flourish where they are without interference.

The Current State of Biodiversity

On a Local Scale

In the most recent State of Nature report, published in 2019, 41% of all organisms known in the UK are said to have decreased in population size since 1970, compared to 26% of species increasing their population size. Furthermore, around 15% of species are at risk of extinction in the next 30 years; to put that into perspective, that is around 10,500 species eradicated. Lost forever.

On a National Scale

The International Union for Conservation of Nature (IUCN) has kept a "red list" of threatened species since 1964 (Diagram to the left). More than 142,000 threatened species have been assessed and 29% are considered endangered, which means they have a very high risk of extinction.

Why has this Impact been observed?

Climate change - Many animals have been unable to survive alongside the devastating impacts of climate change such as polar bears and the lack of arctic ice.

Overhunting/overfishing - Overfishing is when fish are caught from their original habitat in large quantities for commercial use, depleting population sizes. Reducing their population disrupts the food chain, leading to a trophic cascade.

Deforestation - Trees are a natural habitat for thousands of species including plants and animals so their removal displaces animals and kills plants. In addition, smaller habitats mean that the biodiversity density increases, causing more competition and subsequently more species dying of hunger, thirst and a lack of habitat.

Why is Biodiversity important to the World?

Controlling Climate Change

All plants in the rainforests photosynthesise, taking in CO2 and instead replacing it with O2. CO2 is a greenhouse gas so causes temperature rises. When short wave ultraviolet radiation from the Sun meets the layer of greenhouse gases, it transmits them. The earth than absorbs this UV radiation and re emits the energy as infrared waves or, heat. Unfortunately, the CO_2 absorbs around 87% of this heat and transmits the other 13% back out of the Earth's atmosphere. The remaining energy is returned to the Earth causing temperature rises which leads to destructive impacts such as sea level rise and ice loss. The plethora of plant species that we keep alive store the carbon in their tissues, preventing the Maldives from being swallowed, the polar bears being drowned and the storms dominating the Earth. In addition, the rainforests are the 'lungs of the world' for a reason. The O2 that they release allows us to aerobically respire; it allows us to stay alive.

Medicines

More than 50% of medicines used in modern therapeutic practices contain substances that originate from plants. Many mass marketed drugs derive from plants including aspirin. Aspirin's main component is salicylic acid, a chemical that is found in the bark of the willow tree. The active ingredient was first isolated by Edward Stone in 1763 who discovered that salicylic acid prevented fevers and blood clots. Also a headache from that gnarly hangover! Furthermore, other medications such as digitalis (or digoxin) have been produced from plants such as the foxglove. Digoxin, discovered by William Withering in 1775, has been identified to reduce the heart rate of an organism but simultaneously increase the intensity of muscle contractions. It has subsequently been used to treat arrhythmia (abnormal heart rhythm). The drug works by making one's beat more stable and by increasing the stroke volume of the heart to ensure sufficient oxygenation of the body. Therefore, it is vital that we preserve all organic matter as we never know whether one of them will revolutionise healthcare forever.

Food Security

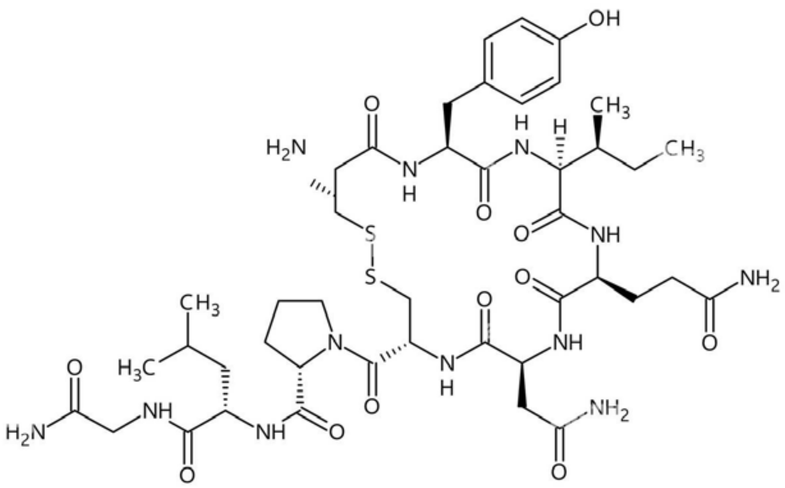
Food security is the ability of a nation to provide sufficient, nutritious food for its population at a reasonable price. Without many of the organisms in our ecosystems, including pollinators, we would be unable to provide enough food for the entire population. Insects such as bees are required to produce almonds, apples, cherries and blueberries as well as many other crops. We need nitrogen fixing bacteria to keep the soil nutritious and a suitable growing condition for crops. Without these natural pollinators, our production of food would be cut by up to one third. A lack of food would cause increased levels of famine. Furthermore, according to simple economics, a lower supply of food with a given demand will increase competition, resulting in increased prices. Like all other organisms we are interdependent with them. Whilst it may seem that animals' relationships with us are purely parasitic, it couldn't be further from the truth. We have a strong mutualistic relationship that we need to embrace. But first things first, let's keep these animals alive.

Edited by Agustya Iyer

Oxytocin—Not Just For Love

How does this curious chemical affect us all?

Ashwin Ravishankar (Y11)



Known more widely as "the love hormone", oxytocin is a peptide hormone and neuropeptide normally produced in the hypothalamus in the brain and released by the posterior pituitary into the bloodstream. It is also available in pharmaceutical form and the drug (Figure 1) is used to stimulate uterine contractions to speed up the process of childbirth. Naturally, oxytocin has proved pivotal in fostering a bond between the mother and the baby, as well as playing a role in lactation. Additionally, our bodies produce oxytocin when excited or in love, and the release of oxytocin during sexual activity is perhaps partly what has earned it the prestigious nickname "the love hormone".

A History of Oxytocin

The first discovery of oxytocin's uterine contracting properties was made in 1906 by British pharmacologist Henry Hallett Dale, and its role in lactation was discovered just five years later. It was the first polypeptide hormone to be sequenced, and its structure was discovered in the 1950s by American biochemist Vincent du Vigneaud, who identified that it was made up of nine amino acids. Many studies have been conducted that prove and examine the function of oxytocin within our bodies. For instance, studies demonstrated decreased urinary oxytocin levels in children placed in orphanages shortly after birth and decreased oxytocin levels in the cerebrospinal fluid of adult women exposed to childhood maltreatment. Men with a history of early parental separation had altered stress responses controlled by a second hormone, cortisol, when given an injection of oxytocin. Furthermore, studies of the effects of oxytocin determined a link between oxytocin and the way men viewed their relationship with their mothers. These tests show arguably distinct evidence of a connection between oxytocin and mental well-being, and therefore perhaps hints at oxytocin playing a role in psychiatric disorders.

Oxytocin in Human Behaviour

In more recent years, oxytocin has been discovered to be more than just a "love hormone". The hormone, although primarily linked with sexual love, is linked with what is described to be "warm, fuzzy feelings", which lower stress and anxiety. Oxytocin has the power to regulate our emotional responses and pro-social behaviours, including trust, empathy, gazing, positive memories, processing of bonding cues, and positive communication. Due to its role in social recognition, attachment, and stereotyped behaviours, which correlate with core deficits in autism spectrum disorders (ASD), oxytocin has been investigated for both its role in the pathophysiology (disease process) of ASD and as a potential therapeutic target for these disorders. Studies showed an increase in these pro-social traits when adults were given an oxytocin spray, such as increased generosity in the "Ultimatum Game" by 80%, and these changes were also prevalent amongst adults on the spectrum.

Oxytocin in Therapeutic Treatment

Such positive results, therefore, beg the question - can oxytocin be used in the treatment of therapeutic disorders? Animal studies have shown oxytocin to have an antidepressant-like effect, with there being many psychological benefits. Oxytocin can be used to combat, and perhaps even cure, mood swings and depression through its use as

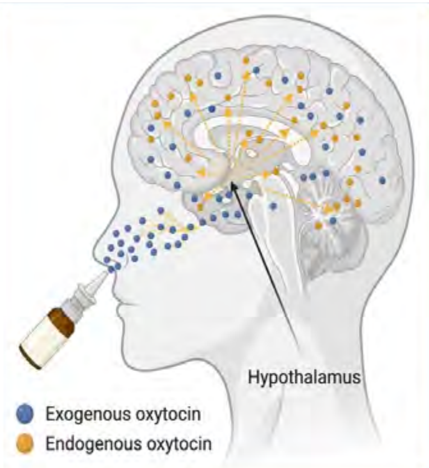


Figure 2 - Distribution of the types of oxytocin with a nasal spray

an antidepressant, and those suffering from major depressive disorder tend to have a lower level of oxytocin in their bloodstream, so oxytocin nasal sprays (Figure 2) may perhaps alleviate the situation. Fear and anxiety can also be dealt with, as the addition of oxytocin reduces stress and efficiently inhibits fear responses by activating an inhibitory circuit within the amygdala (the emotional regulatory centre in the brain). This is because oxytocin enhances pro-social behaviour, which is why it can also help with schizophrenia and other antisocial disorders. Moreover, oxytocin levels were inversely correlated to aggression, perhaps showing the need for oxytocin as a form of therapeutic treatment.

In terms of autism, oxytocin levels were lower in children on the spectrum, with one report suggesting autism is correlated to a mutation in the oxytocin receptor gene. Concerning treatment, clinical trials yielded inconsistent results, yet oxytocin played a role in social recognition in these trials which is a key deficit for those with autism. Studies in rats did show that nasal application of oxytocin can alleviate impaired learning capabilities (caused by restrained stress), and this principle could be applied to humans too. Therefore, many therapeutic diseases including low mood, depression, fear, anxiety, personality disorder, OCD, schizophrenia and even autism can all be potentially alleviated with oxytocin.

Caveats and the Future

Oxytocin is known as the "happy hormone"—encouraging neural growth in the brain—which explains why it can be used in therapy treatment. However, as with all things, there are potential caveats and warnings. A particularly noteworthy point is that although the clinical trials did show elements of change, not all of these experiments were successful and did show change. As well as this, injections of oxytocin cannot always pass through the blood -brain barrier. There are also natural ways of releasing oxytocin, such as listening to music or doing exercise, according to Harvard Health. Experiments have shown the positive social impact of oxytocin, but not necessarily its ability to cure a disorder, as results are solely based on the fact that there is a correlation between a disorder and lack of oxytocin. However, the future does look optimistic, and research seems to be heading in the right direction for "the love hormone".

Edited by Arnav Prasad

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