THE WILSON'S INTRIGUE

STEM Issue 4 : Friday 26th February 2021

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Welcome

It has been over a year since we released our first issue of the Wilson's Intrigue, the school STEM magazine written by students for the students. We would never have guessed a year ago that we would be facing a global pandemic. However, during these trying times, we should recognise the role of scientific innovation in our society as we seek to control the pandemic and try to adapt to the new normal.

This issue, we have 23 excellent new articles for you to enjoy. We hope that, after reading them, you will agree with us when we say that issue 4 is our best issue yet.

We also have lots of exciting things planned for the future. Issue 5 will have a new editorial team, led by Divy Dayal, and a number of new writers.

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

Thank you to Mr Carew-Robinson, Mr Benn and Miss Roberts for their help in confirming the scientific accuracy of the articles. Thank you also to Mr Lissimore for helping publish this magazine and to Dr Whiting for letting us use S5 for our meetings.

**"Nothing in life is to be feared,
it is only to be understood.
Now is the time to understand more,
so that we may fear less."
— Marie Curie**

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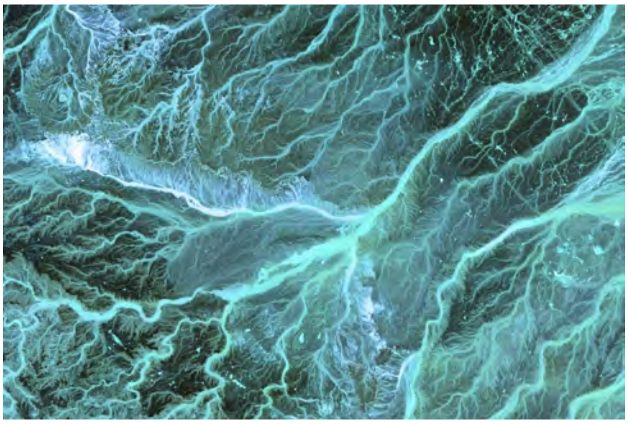
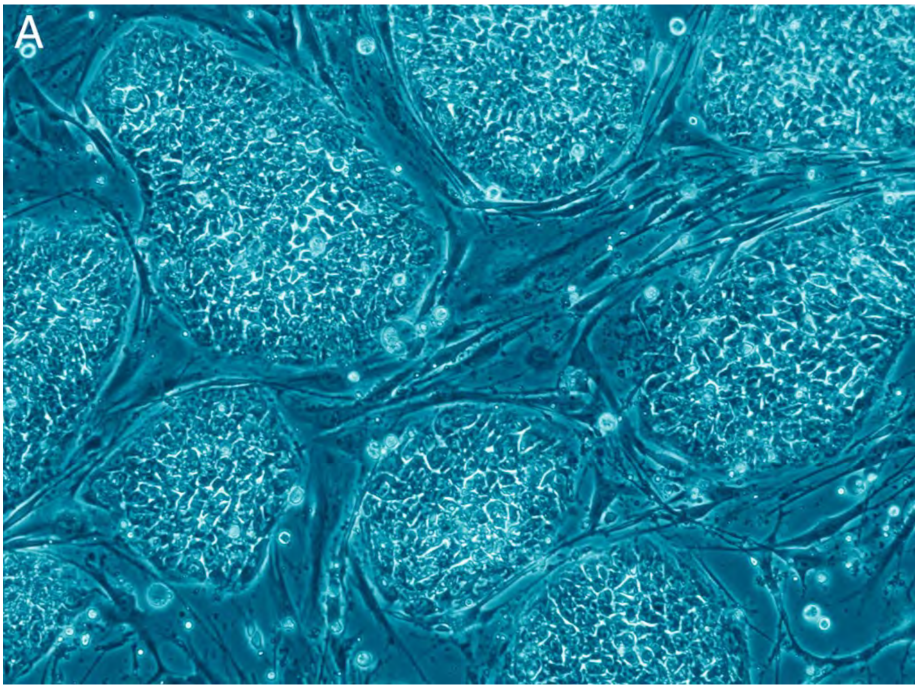


PHYSICS

REFLECTIONS

DID YOU KNOW...

Hydroponics is an increasingly popular way to grow food. The system uses 90% less water than traditional farming and no soil. This is because hydroponics is a method to grow without using any soil, usually with either plants suspended in water or even air! This is a very high-tech way, usually heavily assisted with computers and sensitive technology which closely monitor the growth of the plants. The cumulative effect being healthier, bigger plants!



Human Embryonic Stem Cells (Pluripotent)

Bioprinting

The Future of Tissue Regeneration

Aditya Chougule (Y12)

Since the 1990s, a concept known as "tissue engineering" has been generating a lot of excitement within (and even outside of) the scientific community. It refers to the possibility of replacing faulty tissues and organs with fully-functional replacements that have been printed externally using the patient's own cells.

The prospect of bioprinting—a niche sector that could see massive growth in the next decades and potentially impact millions in the future—is upon us. While we already have 3D-printed prosthesis that can allow amputees to walk and throw, bioprinting allows for the printing of actual body tissues using the stem cells of patients. In this article I will discuss how bioprinting came to be; outline some of the obstacles faced in the development process; and present an example of how the technology can aid the medical field.

The discovery of induced pluripotent stem cells—adult stem cells that have been genetically reprogrammed to an embryonic stem cell-like state—means that we can now generate pluripotent cells from accessible tissues in the body. For example, after a knee reconstruction, pluripotent cells can be isolated from adipose (fat) tissue in the knee (a material which is usually discarded), which could be used to help build 3D-printed replacement organs for other parts of the patient's body.

The next hurdle is actually assimilating the cells with polymer structures in order to replicate tissues within the body. One solution to this is hydrogels. These are jelly-like materials widely used for tissue engineering due to their compatibility with cells—many types of living cells can grow happily inside these hydrogels. However, they lack the viscosity and strength to hold their shape after printing. To combat this, multiple-component composite hydrogels, such as alginate (from seaweed) blended with gelatine, have been developed to improve the gel-like characteristics and enable high resolution printing of free-standing hydrogel constructs.

The technology used to print living cells was developed by the Biofabrication team at the University of Wollongong in Melbourne, Australia. Their idea consisted of extrusion printing (where a material is selectively dispensed through a nozzle) with a co-axial tip. This allows structures to be fabricated out of multiple materials with the more sensitive component (the living cells contained within the hydrogel) being encased by a 'shell' material designed to hold the structure together and protect the delicate entities contained within. This

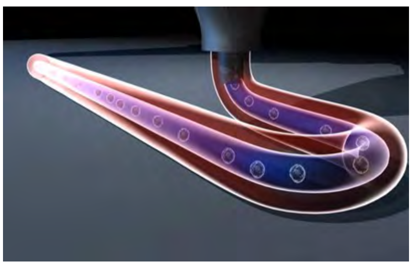


Figure 1: Extrusion printing

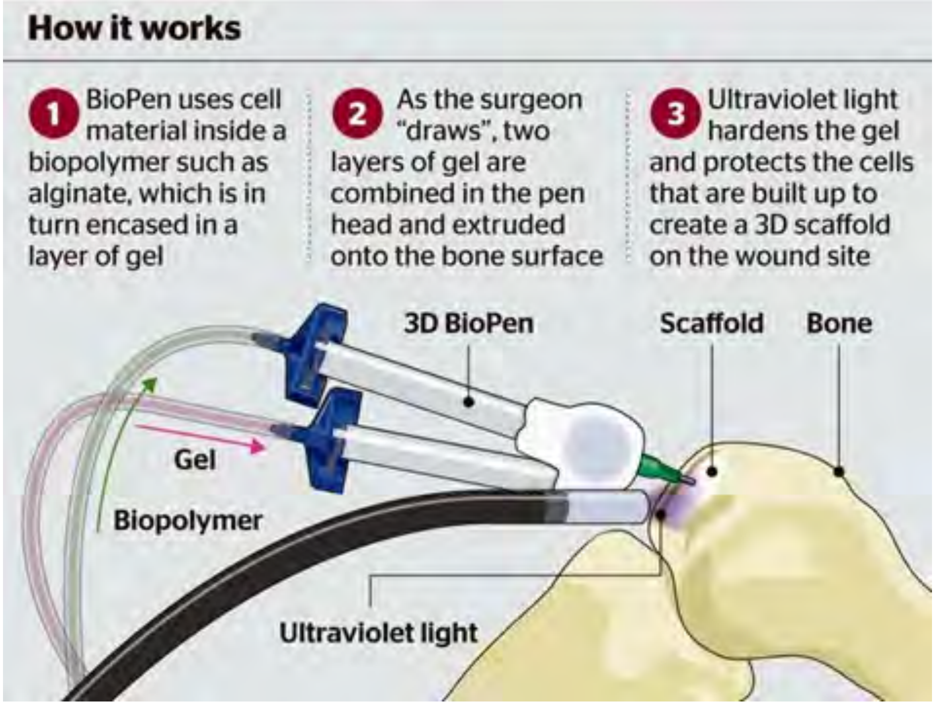


Figure 3: Cartilage Regeneration using the BioPen

technology was then adapted for the operating theatre through the innovation of the BioPen (at St Vincent's Hospital in Melbourne, Australia), which is a handheld device allowing free-form bioprinting to be applied in a surgical context. It is fitted with the same co-axial tip, enabling the deposition of living cells and biomaterials in a manual, direct-write fashion.

Not only can this manually-operated tool allow for surgical sculpting with increased dexterity, the flexibility of in situ biofabrication allows for free-form construction of supplant tissues, providing many advantages over robotically manipulated surgical bioprinters—more cumbersome devices which are harder to sterilise and keep sterile.

Articular cartilage—the substance that coats the surface of bones in joints such as the knee—is an example of a tissue that can be engineered through bioprinting. There is a substantial need for this kind of critical cartilage repair since there are very few resident stem cells available within articular cartilage, meaning there is little chance of cartilage regeneration once it is damaged.

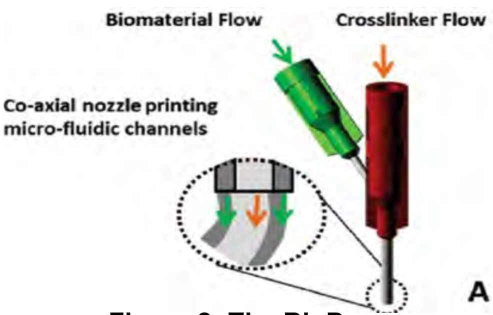


Figure 2: The BioPen

Researchers like Professor Jos Malda at the University of Utrecht in the Netherlands have used the technology highlighted above to create UV-curable biopolymers (where the gel-like fabrication is solidified with UV rays), which have increased scaffold strength five-fold. They can place this material on top of ceramic scaffolds that support the underlying bone and give the artificial cartilage a fighting chance by preventing crushing in the early phases of implantation.

Taking this further, extensive research is also focusing on reducing the movement of these scaffolds by fixing them to the surrounding tissue with various biological 'glues'—natural polymeric materials that act as adhesives. With a sustained push to translating these materials from animal trials (currently these scaffolds are widely used in repairing cartilage damage in race horses) to clinical outcomes, cartilage could quite easily become the first mass printed engineered tissue in the coming years.

3D bioprinting is multi-disciplinary in nature: scientists need to be able to communicate with engineers, who must communicate with cell biologists, who must communicate with clinicians. If we can successfully coordinate efforts between these professions, then the use of this hugely exciting and promising technology as a treatment in the future will be inevitable.

Edited by Michael Lowe

COVID-19 in Mid-2020 and the Race for a Vaccine

Daniel Wan (Y13)

In late February of 2020, I wrote an article for Issue 4 of the Wilson's Intrigue, titled "Coronaviruses - SARS, COVID-19 and the Responses" which compared the responses to SARS and COVID-19, diseases caused by related coronavirus pathogens. Around this time, global attention was beginning to move away from China as outbreaks of the COVID-19 disease began occurring in various other countries - on 25 February, the number of newly reported cases in mainland China was exceeded by those outside China for the first time [1}. In spite of seeing the quarantine restrictions in Hubei Province in January, it still seemed unlikely that such "draconian" measures would be seen in the West. Alas, the notion of Hubei Province being "sacrificed to save the world" has been proven otherwise. Five months later, the situation has shifted drastically – as of 18 July 2020, there have been a total of 14,272,560 cases and 601,062 deaths,[2] figures that will regrettably continue to increase.

The Response in the UK

On 11 March 2020, COVID-19 was declared a pandemic by the World Health Organisation, taking into account its truly global extent [3]. Perhaps the most significant policies enacted to counter the spread of COVID-19 were the large-scale lockdowns put in many locations across the world, akin to those in the People's Republic of China.

In the UK, it was from mid-March that serious lockdown policies began to be put in place, including the closure of schools by 20 March, and the announcement of the first enforceable restrictions on 23 March [4]. Since then, the UK has experienced an incredibly severe outbreak, exemplified by the fact the country currently has the world's second-highest death rate *per capita* among major countries [5]. This is something that several medical experts have attributed to government slowness on testing, tracing and isolating people, which in turn hindered the enforcement of social distancing. As Professor Helen Ward of Imperial College London put it: "We have been playing catch-up from the start." [6] Additional issues with the government response were also highlighted with the slowness of informing the public about COVID-19 symptoms (most notably, a loss of taste and smell, which was added to the UK's list of symptoms more than a month later than in France), the short supply of personal protective equipment for health workers [7] and the handling of care homes – problems that many people will have seen in the news.

The unprecedented measures of lockdown have been the subject of much debate, particularly due to the large social costs they inflict, while the benefits cannot be as easily observed. Several analysis studies, such as those conducted by Flaxman et al. (2020) [8] and Hsiang et al. (2020) [9], have concluded that major non -pharmaceutical interventions and lockdown in particular have had a large effect on reducing transmission of COVID-19, although the data utilised does have some limitations: information on deaths is still incomplete, limited to eleven and six countries respectively, and subject to further consolidation. Regardless, as the UK government response has demonstrated, testing and consequent insight into an outbreak is also vital, especially in its early stages.

The Need for a Vaccine and Basic Principles

Whilst these measures have been determined to have contributed to the lessening of the impact of the disease upon public health, at this point in time they will not eradicate COVID-19. Additionally, their effects upon the economy and society are undoubtedly damaging, and thus it would be inconceivable to keep all of humanity in a perpetual state of lockdown until the disease vanishes from existence. Consequently, it is widely believed that a vaccine is needed to bring the pandemic to an end. According to Peter Piot, a renowned Belgian microbiologist who has dedicated his career to fighting infectious disease, "Without a coronavirus vaccine, we will never be able to live normally again. The only real exit strategy from this crisis is a vaccine that can be rolled out worldwide." [10] Work on such a vaccine has started ever since the release of the genetic sequence of the virus on 10 January 2020. [13]

The basic principle of any vaccine is to trick the body into thinking it has been infected by a pathogen, eliciting a primary immune response as an antigen is detected. The specific antibodies produced following vaccination will remain in the immune system by B lymphocyte memory cells after the infection is gone. If an infection by the real pathogen occurs, the corresponding cells rapidly produce the antibodies in large quantities in a secondary immune response, preventing the onset or limiting the disease. [11]

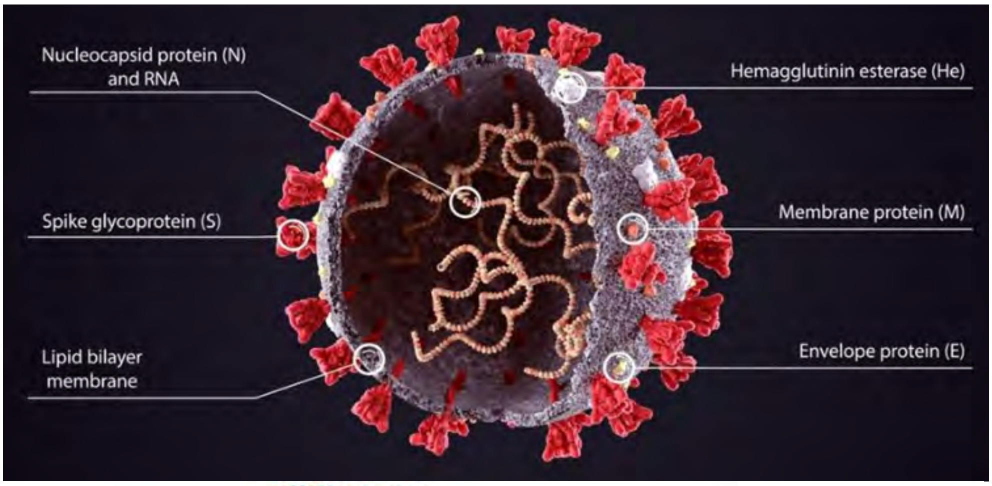


Figure 1 – A 3D illustrated diagram of SARS-CoV-2. Note the spike glycoproteins.

Image Credit: Orpheus FX / Shutterstock

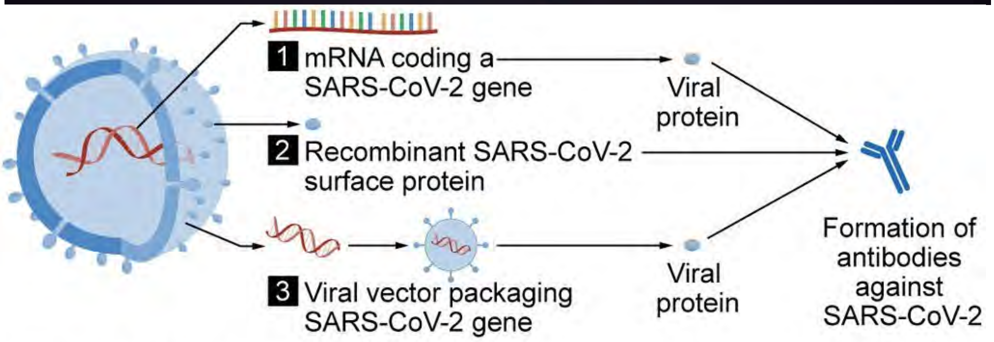


Figure 2 – Vaccine candidates use different mechanisms to prompt the body to produce antibodies against SARS-CoV-2.
Source: GAO-20-583SP

Developing the Vaccine

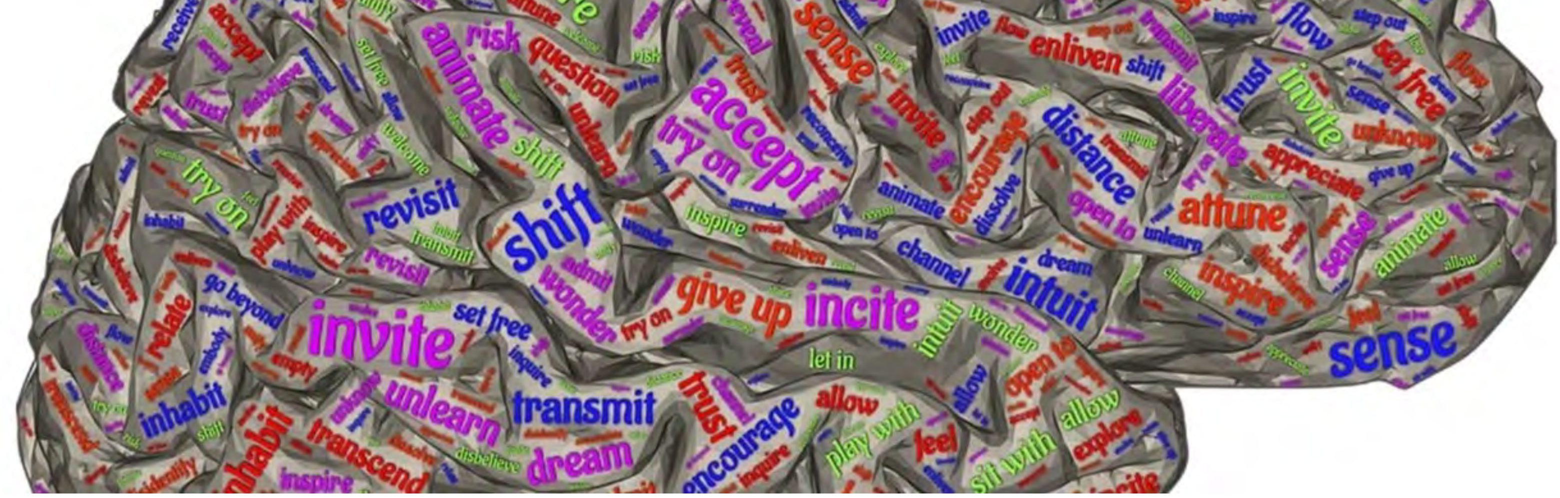
One of the main features targeted in the race for a vaccine is the spike glycoprotein on the capsid of SARS-CoV-2 viruses (the pathogen responsible for COVID-19), identified as an antigen. These spike proteins are able to attach to angiotensin-converting enzyme 2 (ACE II) receptors in the epithelial cells lining the respiratory system, providing a point of entry after a conformational (shape) change. [12]

A variety of approaches to using the spike protein have been taken by the approximately two hundred groups involved. The vaccine developed by Oxford University for example involves the injection of DNA for the spike protein into the blood, which is taken up by cells to manufacture the spike and trigger an immune response. The DNA is delivered through an adenovirus viral vector – a modified chimpanzee virus able to enter human cells, but unable to replicate or cause disease.

Other approaches include that of Moderna, a US biotechnology business, whose vaccine involves the use of mRNA (which is directly transcribed into the viral protein) for this purpose instead of DNA, and of the University of Pittsburgh, where the spike protein itself is delivered by a microneedle patch, which is applied in a manner similar to a plaster. [13] As of 8 June, at least 18 different vaccines are undergoing human clinical trials after pre-clinical tests demonstrated that they were effective in animal models [14]. Data from these trials suggests that some vaccines trigger the production of killer T cells as well as antibodies. Whilst this is promising, there is still a long way to go in checking the safety of the vaccine and its overall efficacy. This process cannot be rushed, and estimates put COVID-19 vaccines as being available in 12-18 months [14] – an incredible feat when considering that vaccines often take in excess of 10 years to be developed and approved.

Unlike previous diseases caused by coronaviruses, namely SARS and MERS, COVID-19 has caused social and economic disruption on a truly worldwide scale: the global economy has been plunged into its worst recession since the Second World War [15]; global famines are projected to affect 265 million people; and geopolitical tensions between China and the west have been heavily exacerbated at a time when cooperation is needed. The response of the UK Government, while successful in some regards, has nonetheless been particularly slow in several key areas of handling the outbreak, leading to dire results. Vaccines represent the only real pathway out of this pandemic, and there are numerous candidates already making their way through human clinical trials. Even so, it will be difficult to truly predict when these vaccines will be ready, or indeed the full outcome of this pandemic. One thing that can be stated with certainty is that the global impact of COVID-19, whether social, economic or political, has been and will continue to be tremendous.

Edited by David Kuc



The Science Behind Intuition

Divy Dayal (Y12)

Call it instinct, sixth sense, clairvoyance or a hunch, intuition is that feeling when you understand something spontaneously, without the need for conscious reasoning [1]. Individuals can make successful decisions without deliberate analytical thought, as Carnival's CEO Micky Arison said "gut" was the primary reason for the $5.45 billion acquisition of Princess Cruises—which ended up to be the most fruitful decision in his career. But what is it?

Throughout history, intuition was regarded to be in-built and inherent, best showcased in Robert Louis Stevenson's 'The Strange Case of Dr Jekyll and Mr Hyde.' Here Mr Hyde's natural urges (i.e. his intuition) leads to his abhorrent crimes. While the Victorians may have blamed the shape of someone's head to be the reason for their awful personality (phrenology), they were correct in saying that intuition is a fundamental part of our behaviour. Current research shows that 90% of critical decision making are made using our intuition[2]. Ergo, intuition is something we should harness, cure and better to make our decision making as finessed as possible.

"It's different from thinking, it's different from logic or analysis ... It's a knowing without knowing." – Sophy Burnham, bestselling author of The Art of Intuition

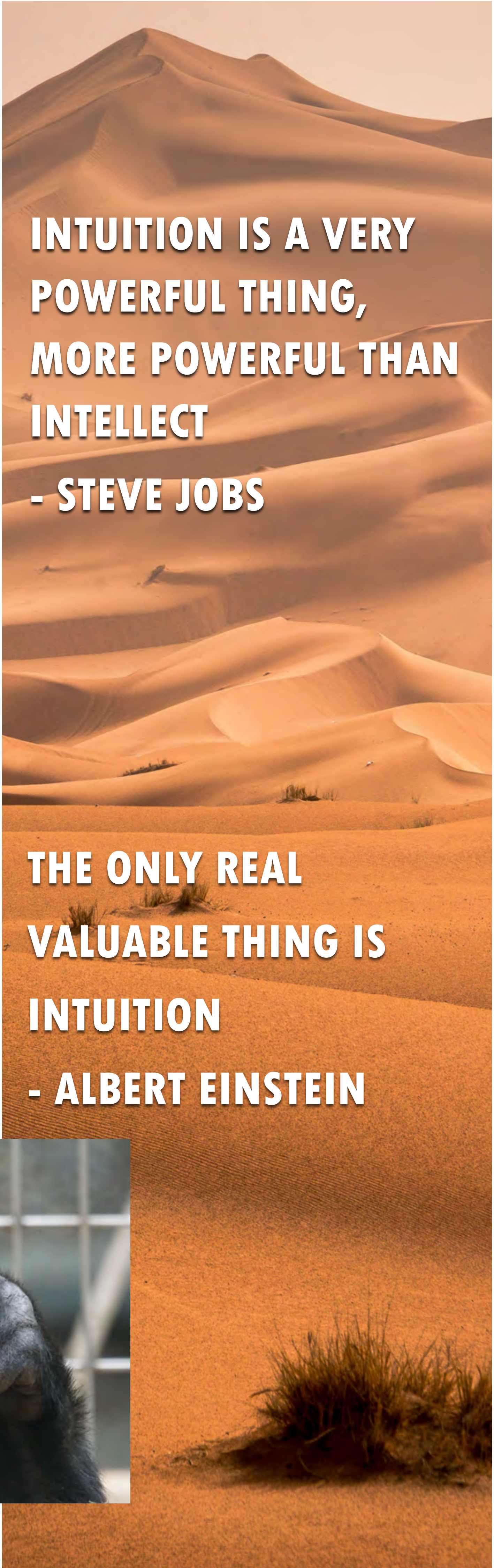
As Editor-in-Chief Arianna Huffington puts it in her upcoming book Thrive:

Even when we're not at a fork in the road, wondering what to do and trying to hear that inner voice, our intuition is always there, always reading the situation, always trying to steer us the right way. But can we hear it? Are we paying attention? Are we living a life that keeps the pathway to our intuition unblocked? Feeding and nurturing our intuition, and living a life in which we can make use of its wisdom, is one key way to thrive, at work and in life.

How do we make best use of our intuition?

It is critical to understand that there are different types of intuition, which typically occupy the right side of brain (i.e. the creative side), which is why: 'Creativity does its best work when it functions intuitively," writes researcher and author Carla Woolf. Scientists believe that intuition also operates through the hippocampus and the gut (thus the idiom "gut feeling"). However, it can be difficult to understand the types of intuition since Western education methodologies focus primarily on left brain skills (memory and analytical thinking). There are many ways to tune your intuition, including meditating and impulse activities; all rely on 'listening' to the inner voice.

Intuition Peak in Antarctica is so named "in appreciation of the role of scientific intuition for the advancement of human knowledge[3]



Studies at Yale university examined nonverbal communication against people with and without intuitive abilities, and subjects with intuitive abilities responded quicker and couldn't explain their rationale. It is interesting to note however that level of accuracy did not change between the two groups[4].

All in all, intuition is incredibly hard to quantitively discuss, and there is no scientific evidence of its existence – only subjective evidence that we all have experienced. It is our call to listen to this inner voice.

Instinct

Instinct and intuition are synonymous in every day vocabulary, however there is a nuanced difference. Instinct is often misinterpreted as intuition and its reliability considered to be dependent on past knowledge and occurrences in a specific area. For example, someone who has had more experiences with children will tend to have a better instinct about what they should do in certain situations with them. This is not to say that one with a great amount of experience is always going to have an accurate intuition [5].

Instinct is something that is completely natural and is the direct result of genetics and evolution. All organisms have instincts, and these can be highlighted when there is a sudden change in environment: in a desert, due to the sun, instinct would tell to remove unnecessary clothes to cool down. Instinct is what has been hardwired into our bodies, regardless of whether it is beneficial for us or not.

Edited by Utkarsh Sinha

Robotics in Maxillofacial Surgery

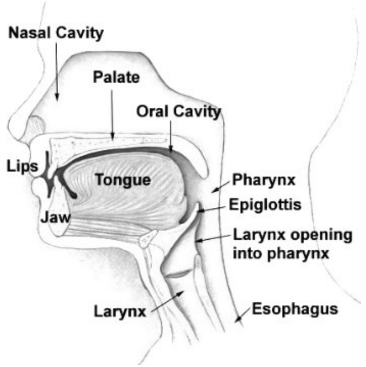
Mohamed Ahmed (Y12)

Robotic Surgery

It is difficult to argue against robotic surgery being one of the most exciting medical developments of the century- with rapid development from Mouret's first laparoscopic cholecystectomy in 1987[1] to the widely used da Vinci surgical system. These developments have revolutionised surgery resulting in less complication, less time spent in hospital, lower morbidity and better cosmetic results during such procedures; due to these sought after benefits, oral and maxillofacial surgery (a medical and dental speciality for reconstructive surgery for facial trauma [2], the oral cavity, head, neck and jaw) is one area where robotic surgery is in development despite the many challenges that will be discussed.

What are the present issues with Maxillofacial Surgery?

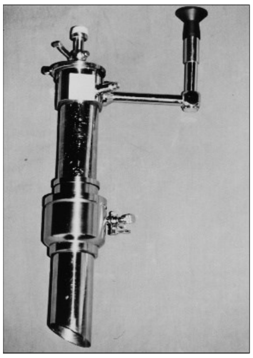
The largest issue with this form of surgery is the invasive procedure - to conduct the surgery, incisions in the lower jaw (transmandibular) or pharynx (transpharyngeal) have to be made. These points of incision are problematic due to the surgical morbidity of potential blood loss, speech dysfunctions and indigestion (dyspepsia).



The pharynx can be seen behind the throat and [3]nasal cavity

The Challenges of Previous Minimally Invasive Solutions

In 2000, transoral laser microsurgery was tested and advocated by a number of surgeons.



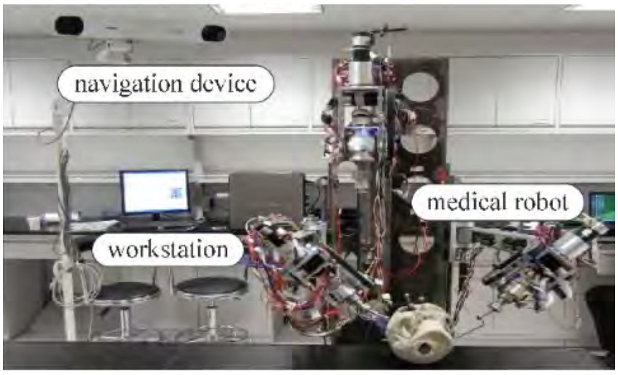
A modified rectoscope used for the first laparoscopic cholecystectomy

making incisions in the oral cavity, morbidity was decreased and the use of smaller incisions through the laser was introduced into maxillofacial surgery. However, its reliance on microscope-based visualisation hindered its

use as it relied on being able to see the area of work in the surgical field.

Later on, in 2009, transoral [4] robotic surgery (TORS) was approved by the FDA for use in stage T1 and T2 of oropharyngeal cancer- cancer of the aforementioned pharynx- for the same reasons as transoral laser microsurgery. Despite this, robotic surgery still lacked the neurovascular control (ability to make finer motions and supress natural human tremor) to protect the nerves and blood vessels in the surrounding area- such as the buccal nerve which is at risk during some wisdom tooth extractions- thus never becoming widely adopted.

Benefits of Robotic Assisted Maxillofacial Surgery Today



A modern developmental maxillofacial surgery

At the moment, developing surgical systems go beyond the issues of the past and are soon to be implemented into future maxillofacial treatments. The lack of exposure associated with laser microsurgery has been remedied with a three-dimensional [5] view that is magnified by 10-15 times to allow precision. The precision of movements and the ability to supress[6] the natural tremor of a surgeon's hand have allowed appropriate and superior neurovascular control through the set of articulated arms. This has finally made it viable for larger range introduction into maxillofacial surgery allowing for less invasive treatment and economisation of medical staff (as only one surgeon, two nurses and an anaesthesiologist are needed regardless of the difficulty of the operation)

Limitations

While the technology is impressive, there is still a long way to go until it is perfected. The lack of haptic (touch-based) feedback within all designs leads to difficulty in some motions such as tying which has been show to lead to an increase in suture breakages because of unintended excess tension which is applied.

Furthermore, the technology has still yet to adapt to the maxillofacial field (having been most commonly use in prostatectomies) and lack some basic tools such as bone saws and drills needed for many treatments such as those for maxillofacial fractures and craniofacial asymmetry.

Lastly, the cost of these systems restricts their use: costing $1.5million to purchase; needing to be maintained for $100,000 annually and $200 of disposable tools for each patient. As most new medical technologies, medical entities have to consider when this technology will be deemed developed enough for investment and widespread use.

Edited by Divy Dayal

CBT-I: The most effective treatment for insomnia

Anussan Nadarasa (Y13)

As one of the most common sleep disorders, insomnia is highly prevalent in the global population. Depending on the diagnostic criteria used, between 10 to 15% suffer from insomnia disorder, while 30% to 48% show symptoms of insomnia (Ohayon, 2002; Roth et al., 1999). There are several models for the aetiology of primary insomnia, but most of these stem from the concept of insomnia as a disorder of hyperarousal. This is where the individual with insomnia exhibits a level of arousal that is 'incompatible with the initiation and/or maintenance of sleep' (Gehrman et al., 2012; Riemann et al., 2009). Common symptoms of insomnia, beyond an inability to initiate or maintain sleep, include poor psychomotor performance, irritability, reduced motivation, and impaired daytime functioning, caused by daytime fatigue and concentration issues. These all contribute to a reduced quality of life (Bonnet et al., 2006). The two primary treatments to alleviate the symptoms of insomnia are cognitive behavioural therapy for insomnia (CBT-I) and pharmacotherapy.

> **"Common symptoms include poor psychomotor performance, irritability, reduced motivation, and impaired daytime functioning..."**

CBT-I is a multicomponent therapy that uses cognitive and behavioural techniques to target the factors specifically related to insomnia (Baron et al., 2017). It usually includes two or more treatments. Although the interventions included in CBT-I packages vary, they typically involve a behavioural intervention, such as stimulus control or sleep restriction (SR); an educational intervention, namely sleep hygiene; and cognitive therapy. Stimulus control is a series of measures that eliminate non-sleep activities from the bedroom to create a sleep-conducive environment. SR is when the prescribed time in bed is abruptly reduced to gain better sleep consolidation. Sleep hygiene is a series of daytime and near-bedtime activities whose omission, reduction, or commission enables sleep. Cognitive training teaches the patient to self-regulate bedtime and daytime thoughts about sleep to diminish cognitive arousal (Lichstein et al., 2012). In terms of the implementation of the treatment, CBT-I sessions are usually 30 to 60 minutes in duration, typically with 4 to 8 sessions in total. The sessions are delivered on a weekly, or sometimes biweekly basis, by healthcare professionals trained in providing CBT-I. Although CBT sessions are mostly delivered in person and individually, it can also be delivered in a group setting or via telephone consultations

Advantages of using CBT-I to cure insomnia:

The improvements in sleep brought about by CBT-I are better maintained in the long-term, following discontinuation of therapy, than those brought about by pharmacotherapy. This was illustrated in a meta-analysis published by Morin and colleagues

(1994) of 59 studies that included over 2000 patients in total. The acute clinical improvements of CBT-I were later not only sustained but also enhanced, after active treatment was discontinued, at the 6-month follow-up assessment. For instance, the mean percentage change from post-treatment to follow-up was -10% for sleep-onset latency (SOL) – the time taken to initiate sleep – and 5% for total sleep time. Riemann and Perlis (2009) noted that this post-treatment enhancement of the assessed sleep parameters was ‘truly remarkable for brief interventions consisting of 6–8 therapy sessions.’ More recent studies also corroborate the aforementioned results. Riemann and Perlis (2009) reviewed five studies that compared CBT-I with pharmacotherapy, including one that showed that the improvements of CBT-I, but not pharmacotherapy, were maintained over 24 months of follow up, following the completion of the treatment (Morin et al., 1999). They concluded that behavioural treatments, like CBT-I, sustain longer-term gains than pharmacotherapy. Therefore, the treatment effects of CBT-I are not only better maintained over time than pharmacotherapy but are also immensely durable in their own right.

CBT-I is also highly effective for older patients with late-life insomnia. A meta-analysis by Pallesen and colleagues (1998) of 13 studies involving elderly insomnia patients found that CBT had statistically significant effects over controls at posttreatment. For instance, the effect sizes of acute treatment ranged from medium to large for SOL, wake-after-sleep-onset and two other parameters. At follow-up, which was an average of six months after completion of active treatment, therapeutic improvements were maintained for all four sleep parameters. Hence, CBT produced significant and lost-lasting improvements in older patients with insomnia. In addition, a study was conducted by Sivertsen and colleagues (2006) that compared CBT with the hypnotic zopiclone, in older adults with chronic primary insomnia. They found that CBT was more effective at both posttreatment and at 6-month follow-up than zopiclone

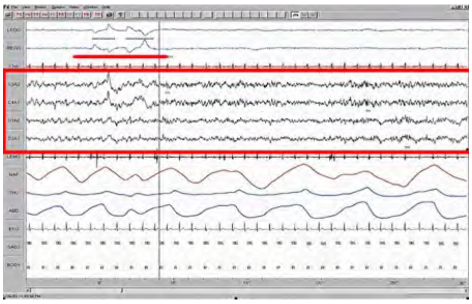


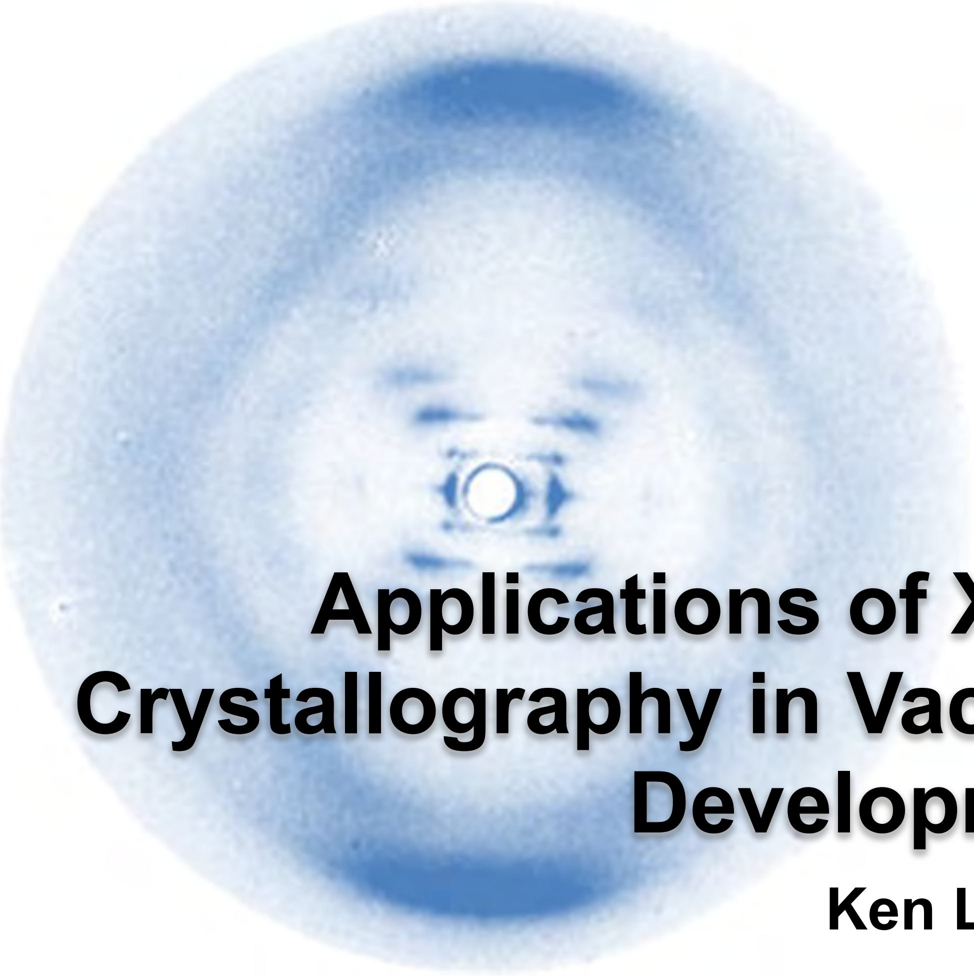
Figure 1—polysomnographic record of REM sleep

monotherapy in improving sleep efficiency and wake-on-sleep-onset. Individuals who underwent CBT also saw significant increases in the deep, restorative stages of sleep, namely slow-wave stage 3 and stage 4 sleep. Since it is well documented that the structure of sleep changes with age, the increase in slow-wave sleep suggests that CBT can improve both sleep structure and sleep duration in older adults (Lichstein et al., 2012). Therefore, older insomnia patients can derive significantly greater benefit from CBT than zopiclone therapy.

Another strength of CBT-I is that it can be tailored to the needs of the patient. For instance, CBT-I can be delivered individually, in a group format, or via telecommunications technology. Studies have shown that all of these modalities are equally effective in improving objective and subjective sleep outcomes (Bastien et al., 2004). For patients who have more complex cases that require additional attention, CBT-I can be delivered individually. This is so that the clinician can identify the factors that are most connected to the patient’s insomnia, which will enable them to develop a personalised CBT-I package that contains the interventions that will be most effective for that specific patient. However, group sessions tend to be more cost-effective for the patient and also allows them to benefit from the support of the other participants (Lichstein et al., 2012). Due to the modular nature of CBT-I, the strategies used can also be customised to each patient’s needs and preferences. For instance, for individuals who have anxiety about the drastic reduction to the time spent in bed that SR requires, sleep compression may be used instead. This is where, instead of an abrupt reduction, there is a gradual reduction in the time spent in bed. This ability to tailor CBT-I is likely to be a contributor to its efficacy rate of 80%. (Smith et al., 2002).

CBT-I is also highly effective at improving a patient’s subjective evaluation of their sleep. In a study conducted by Morin and colleagues (1999), the Sleep Impairment Index, which is calculated from the results of a questionnaire completed by patients, declined by 10 points after 24 months for patients treated with CBT-I, but only by 4 points for patients who took temazepam. This shows that patients were significantly more satisfied with CBT-I than with pharmacotherapy. It must be said, though, that insomnia trials generally find more significant improvements in subjective parameters, which are measured through sleep diaries or questionnaires, than in objective parameters, which are measured through polysomnography. However, this does not diminish the significance of changes in subjective outcomes, since the diagnosis of insomnia is dependent on patient reports of symptoms and not diagnostic laboratory tests. It was also found that a patient’s perception of their sleep quality, regardless of the polysomnography-measured sleep quality, was associated with better next-day performance on cognitive function tests (Reynolds and Ebben, 2017). Hence, a patient’s subjective evaluation of their sleep is an important dimension and CBT-I has much greater effects on subjective outcomes than pharmacotherapy.

Edited by Harsh Sinha



Applications of X-ray Crystallography in Vaccine Development

Ken Li (Y13)

X-ray crystallography is widely heralded as one of the most important contributors towards the discovery of DNA, through the taking of “photo 51” in May 1952 by Raymond Gosling (Watson, 1968, p.14). This allowed Watson and Crick to deduce the final structure of DNA through incorporating previous evidence, now considered as one of the most major breakthroughs in modern biology. Currently, X-ray crystallography is widely used for examining the internal structure of crystallised substances, such as salts, minerals and proteins. Since the mid-20th century its applications in the structure-based design of small-molecule drugs are well known and form the basis of several success stories (Malito, 2015), but it is less well known that **the use of such techniques also forms an important basis for the design of novel vaccine antigens too, through the high resolution mapping of antigens and antigen-antibody complexes**.

It is important, however, to firstly understand the principles by which X-ray crystallography works. X-rays are high frequency electromagnetic waves which have a wavelength short enough to be of the order of the atomic spacing in crystals. Thus, X-rays are able to diffract through the crystalline structure, and the interference patterns produced by the diffracted X-rays are picked up by the detector opposite, which picks up the intensity of the diffracted signal. Since the nature of interference determines the intensity of the diffracted X-rays, and is itself is related to the atomic spacing in the crystal, a relation known as Bragg’s law, the internal structure of the crystal can be constructed by the detector.

In the last decade, vaccine

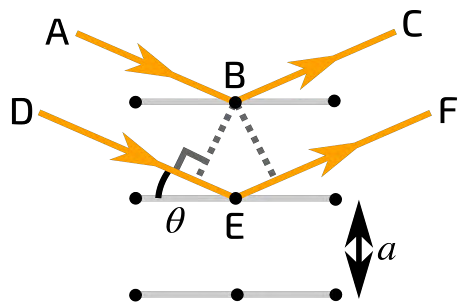


Fig. 1: X-rays interacting with a crystal. See if you can try deriving Bragg’s law, the conditions required for constructive interference, in terms of θ, the atomic spacing a, and the wave-

research has been driven by whole-genome sequencing, which lead to the approach of “reverse vaccinology” (Malito, 2015). This involves identifying particular genes within the pathogenic genome which would make good vaccine targets, such as extracellular proteins, after which the complementary vaccine protein against it can then be synthesised. Rappuolli and others (2000) pioneered this approach through sequencing the Meningococcus B (MenB) genome, which enabled a vaccine to be developed where conventional techniques were not possible due to the unique and diverse structure of the bacterium.

However, the process of sequencing, identifying and narrowing down the viable antigens using this approach is relatively time consuming, and also does not necessarily provide relevant insights into antigen structure and function, information which is vital to designing an effective vaccine (Malito, 2015). Using a structural approach, one can isolate a small subset of suitable candidate antigens by imaging and chemical reactions, which can then be individually mapped out. This is where X-ray crystallography comes in, as a technology which has enabled greater detail in antigen characterisation over the last five years, which facilitates the design of better antigens, more suited to being incorporated into a vaccine to be introduced into our bodies.

Recall that a vaccine often involves using pathogenic antigens or pathogenic genetic material that stimulates antigen production and presentation in our bodies, leading to the stimulation of B-lymphocytes, which produce antibodies and differentiate into B-memory cells to confer artificial immunity to the pathogen (Klenerman, 2017, p.48). The issue with isolating and using antigens directly from the pathogen is that there may be undesirable biological properties of the protein, such as pore-forming toxic activity/catalytic activity, conformational instability that increases the risk of protein aggregation, or an obscure epitope (the site on the antigen where the antibody binds to) (Malito, 2015). X-ray crystallography circumnavigates these issues by providing structural information to find solutions to these potential issues; the rest is a matter of engineering and chemistry to construct the new antigen.

Development of the Respiratory Syncytial Virus (RSV) vaccines are an example of such techniques being put to use. This is an orthopneumovirus, which targets the upper respiratory tract, and is the leading cause of hospitalisation for children up to age five, continuing to infect individuals repeatedly throughout life. Vaccines often focus on targeting the F surface glycoprotein, an antigen which helps he virus evade the immune system. This antigen is a trimer, a molecule made by the linkage of three separate subunits, but its high conformational instability means that the glycoprotein rearranges itself spontaneously from pre-F into a post-F conformation, which hides the epitopes which antibodies would be able to target to neutralise most effectively (Graham, 2019). Thus, researchers investigated the crystal structure of this particular trimer in the pre-F conformation using X-ray crystallography, and managed to identify the highly neutralisation-sensitive epitopes at the apex of the glycoprotein. Further protein engineering revealed a stable pre-F trimer that could be used in vaccines, which were able to retain the epitopes which stimulated the greatest neutralisation activity, and these proved to be 10-100 more neutralising than other antibodies which targeted other epitopes present on both pre-F and post-F conformations (Graham, 2019).

A more relevant example could be applications of this technology in the development of vaccines against coronaviruses, which are a family of viruses with a large spike (S) glycoprotein which is composed of a receptor-binding subunit (S1) and a membrane fusing subunit (S2) (Graham, 2019). Unfortunately, this particular glycoprotein is structurally variable between different viruses, so targeting it with a universal vaccine incredibly difficult. Analysis with X-ray crystallography, however, revealed several residues in the S2 subunit which were proline substituted, and this seemed to lend them homogeneity across most of the coronaviruses (Graham, 2019). By targeting these particular domains with engineered antibodies, an improved immune response was observed in some mice (Graham, 2019), although there is yet to be an approved vaccine on the market for humans.

However it is also important to be aware that X-ray crystallography is not the solution to all vaccine problems. Current efforts in developing a vaccine against HIV are currently focused on envelope glycoproteins, but these are a family of proteins possessing large genetic plasticity and structural variability, which have only been partially solved by X-ray crystallography (Graham, 2019), so this technique is only one part of the multifaceted approach needed to find a HIV vaccine.

Despite this, advances in X-ray crystallography in the last few years have clearly revolutionised vaccine development and helped to find solutions to problems which would not have been able to be addressed by conventional approaches. This is only one example of many, where all scientific disciplines are married together to modernise research and lead us further in the road of scientific discovery, improving our lives and the world we live in too.

Edited by Ray Wang

The Science Behind Pain

Koushikk Ayyappan (Y13)

On a scale of 1 to 10, how painful is it?" Anyone who has presented a complaint to a GP or A&E has probably been asked this question. But what is pain in the first place? How do we know that something is painful? Is pain a feeling or a physiological response?

According to the International Association for the Study of Pain, it is an "aversive sensory and emotional experience typically caused by actual or potential tissue injury", which is as a result of the nociception pathway.

The Nociception Pathway

The feeling of pain is due to a complex physiological response to harmful stimuli called nociception, and is a product of evolution.

Nociceptors are sensory neurons that send a wave of depolarisation to the spinal cord because of the release of chemicals, such as prostaglandins, due to noxious stimuli which activate receptors. The neuron transmits the action potential via the spinothalamic tract to the thalamus, and a third order neuron conducts impulses to the relevant area of the brain, where pain is perceived (see Figure 1, which is a somatosensory representation of the brain, showing where pain in each area is perceived in the cortex).

This forms part of the ascending pathway. However, it is only part of the picture. There is also a descending pathway which can alter our

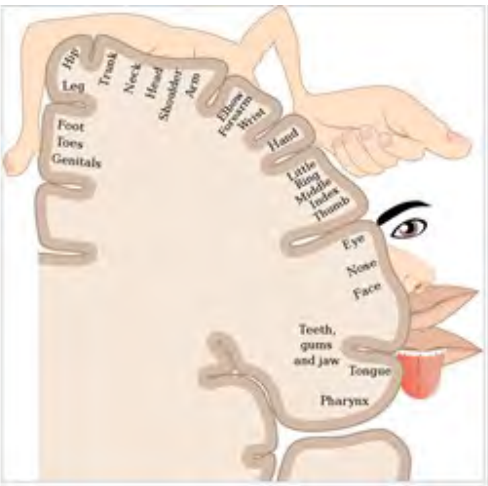


Figure 1: A cortical homunculus

perception of pain and even inhibit it. Between the afferent and second order neurons, as shown in Figure 2, substance P, a neurotransmitter, is released. However, a serotinergic/adrenergic neuron from the brain stem can be activated, which neuromodulates the synapse. Serotonin inhibits release of substance P, whilst noradrenaline excites another opioid interneuron that is in close proximity of the synapse. The release of opioid, called enkephalin, inhibits both the presynaptic and postsynaptic neurons, preventing the pain impulse from being transmitted to the brain.

How To Control Pain

It now seems logical that our sense of pain can be altered—both by our past experiences, and by social and psychological factors, as this can cause inhibition via our descending pathway. This explains why we all have very different perceptions of pain.

Biological factors can also alter this perception. For example, over-the-counter painkillers can interfere with this pathway. Non-steroidal Anti-inflammatory Drugs (NSAIDs) inhibit an enzyme called cyclooxygenase, which plays a role in the formation of prostaglandins. If you remember earlier, prostaglandins are molecules that are released due to damage to tissues, which activate receptors. As the receptors are less stimulated, the pain action potentials are not initiated in the first place. Steroids can decrease inflammation as well as the immune response to tissue damage, although there are more harmful side effects associated with their use.

Opioid painkillers such as morphine work by increasing the concentration of opioid at the synapses of neurons at the spinal cord, so that the presynaptic and postsynaptic neurons are further inhibited and cannot depolarise or propagate action potentials as easily, as the threshold for impulses is harder to overcome.

Where This Pathway Goes Wrong

But where can this loop go wrong? Several diseases and conditions which alter the pathway can lead to interesting consequences for the patient.

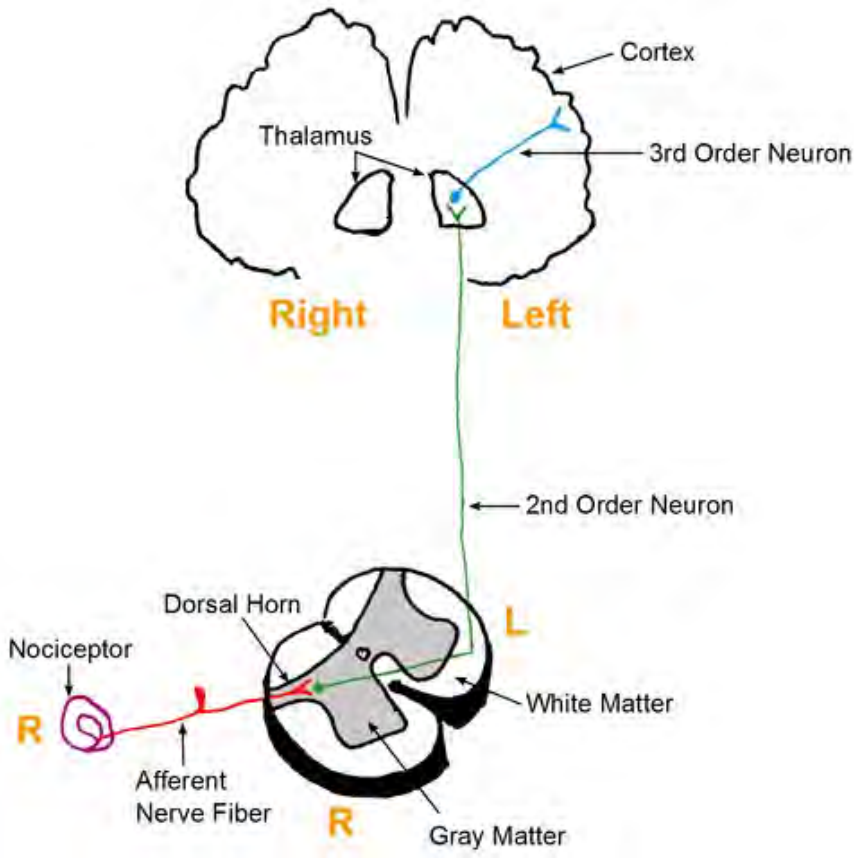


Figure 2: The ascending pathway

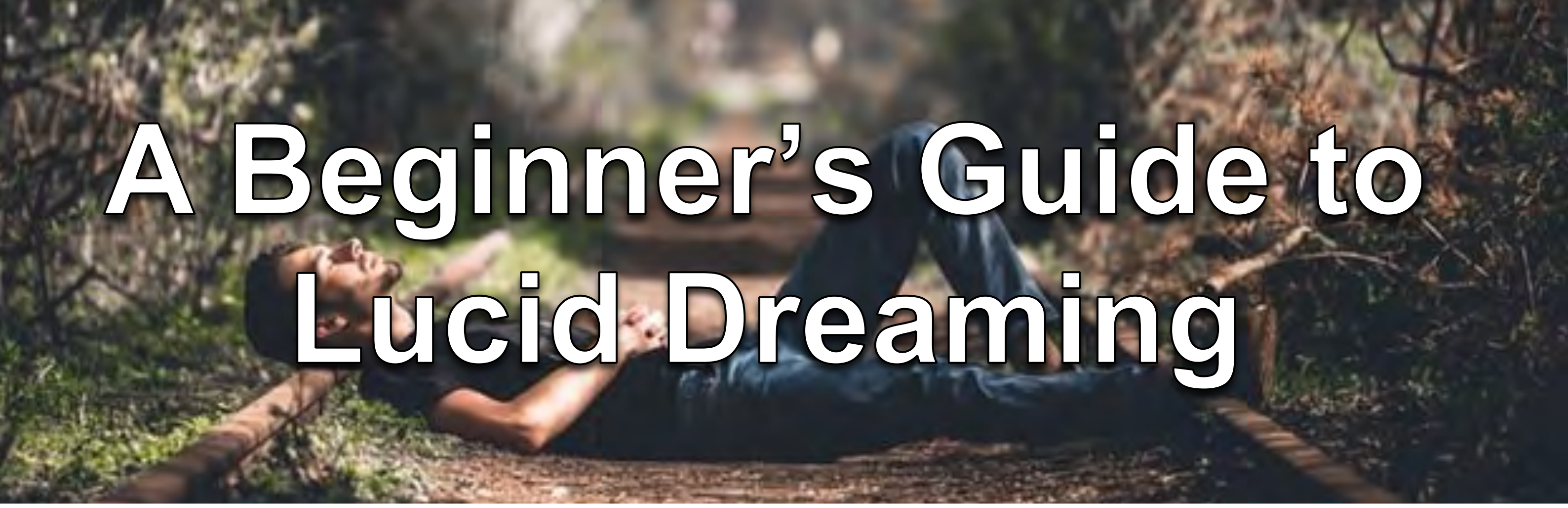
CIPA, or congenital insensitivity to pain with anhidrosis, is a disorder present from birth, characterised by the inability to feel pain and to feel temperature (sweating is impossible, which is the reasoning behind the 'anhidrosis'). CIPA is an autosomal recessive disorder caused by a mutation in the NTRK1 gene, which is the neurotrophic tyrosine kinase receptor. NTRK1 is a receptor for nerve growth factor (NGF), which causes development of axons and dendrites. The mutation in NTRK1 do not allow NGF to bind properly, causing defects in the development and function of nociceptive reception. Therefore, those with CIPA are also likely to have intellectual disability too.

Ever heard of phantom limb syndrome? This is where those that have had an amputated limb or severe nerve damage feel chronic, untreatable pain. It was initially thought that this was due to damage to the peripheral nervous system and nociceptors. However, those born without limbs also have symptoms. This indicates that the cause is elsewhere, and it is hypothesised that the sensorimotor cortex (the part of the brain that is responsible for processing sensory inputs and executing movements) plays a key role in this syndrome, although further research into mechanisms are still needed.

Neuropathic pain is caused by diseases that affect the somatosensory nervous system. It is sometimes characterised by abnormal sensations or pain from normally non-painful stimuli. A multitude of reasons can cause this, such as injury, stroke, multiple sclerosis, metabolic disorders and even cancer. Only 50% of people achieve partial relief, so it is a condition that is difficult to treat. Treatment normally includes a cocktail of drugs such as tricyclic antidepressants and anticonvulsants, but this will simply lead to polypharmacy and there is no current curative method to deal with neuropathic pain.

Despite diseases of pain being very difficult to treat, with current methods mainly involving painkillers, with the rise of technology and scans such as fMRIs, we can now map out personalised brain pathways. This could allow us to control pain and further future treatment looks promising—especially considering that pain research is a growing field of research in medicine and neuroscience.

Edited by Michael Lowe



A Beginner's Guide to Lucid Dreaming

Neel Patel (Y12)

One of the strangest things about dreams is that they can be controlled—the characters, the environment and even the narrative can all be somewhat consciously manipulated while you are unconscious. Here's how you can control your dreams.

What is lucid dreaming?

Lucid dreaming happens when the dreamer is aware that they are dreaming. They can recognise their thoughts and emotions throughout the dream. During a lucid dream, the person may gain some control over their dream and be able to change the storyline and the environment. However, this not necessary for the dream to be classified as 'lucid'.

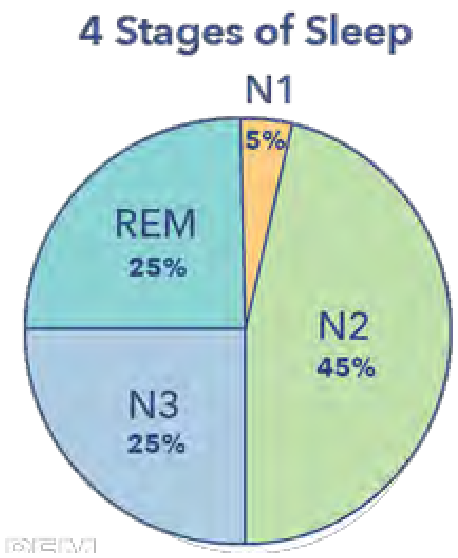
Lucid dreaming, like most dreams, usually happens in rapid eye movement (REM) sleep. In REM sleep, your brain is very active and your heart rate and eye movements also increase. During non-REM sleep, your brain waves, heartbeat, and eye movements gradually slow down.

How do you experience lucid dreams?

Now that you know what lucid dreaming is, you might be wondering how to lucid dream. Well, look no further, this next section is about just that! Since we know that lucid dreaming occurs most commonly during REM sleep, spending more time in REM sleep will increase your chances of lucid dreaming. But how do we accomplish this? It is vital that you practice good sleep hygiene. Examples of this include: maintaining a sleep schedule, avoiding electronics before sleeping, exercising daily and creating a relaxing environment to sleep in.

Another way to aid lucid dreaming is to keep a dream journal. By writing down your dreams, you are forced to recall them and this action helps increase your brain's awareness about dreaming. To keep a dream journal, write down your dreams in a notebook shortly after waking up. Read through the journal to familiarise yourself with your dreams.

Have you ever wondered why some things just don't make sense in dreams: you can't run quickly and you can't punch hard? You can actually use this to your advantage. Performing a reality check, such as pushing your fingers against the opposite palm (in a dream, they will pass through) or pinching your nose (in a dream, you will be able to breathe), multiple times per day can help to train your mind to recognise your own awareness while you are awake. A study



conducted by Dr Asby describes reality testing as verifying whether you are in real life or in dreams.

In the popular movie *Inception*, a spinning top is used as a reality check. If the top keeps on spinning, the characters know that they are in a dream. If not, then they are awake. However, for actual lucid dreaming

purposes, this is not a very good reality check.

Another technique that Asby describes is 'waking back to bed' (WBTB). This is an induction technique and can be done by waking up five hours after bedtime. When you go back to sleep, you'll be more likely to enter REM sleep while you're still conscious. Another induction technique is 'mnemonic induction of lucid dreaming' (MILD). Tell yourself that you will lucid dream tonight. You can do it before bed or when you're awake during WBTB

By using a mixture of these methods (dream journaling, reality checks and induction techniques), you can become conscious during your dreams. If you are conscious, you can interact with and direct your dreams.

What are the benefits and risks of lucid dreaming?

Lucid dreaming has a lot of benefits such as its ability to decrease and relieve nightmares. Frequent nightmares often affect people with stress, anxiety, depression, PTSD and other mental health problems. During a lucid dream, the person is able to understand that the nightmare isn't real. The dreamer can also control the dream, which allows you to turn a nightmare into a more neutral or pleasant scenario.

Visualizing physical movements can increase a person's actual ability to do them. This can be done during a lucid dream, where the dreamer can mentally practice motor skills. When you perform these motor skills while dreaming, your brain's sensorimotor cortex becomes activated. This is the part of the brain that controls movement.

In this example, lucid dreaming could help to promote physical rehabilitation for people with physical disabilities. It may also benefit people without physical disabilities by improving sports performance and other motor skills.

Lucid dreaming is generally considered safe, but there are some risks for people with mental health disorders. These risks include: sleep problems (since lucid dreaming techniques purposely interrupt sleep, getting enough sleep can be difficult. The risk is higher if you have a sleep disorder); derealisation (lucid dreaming induction intertwines reality and dreaming, making it difficult to determine what's real); and dissociation (the overlap between reality and dreaming can also cause disconnection from your surroundings or self.

Edited by Michael Lowe

Treat the Patient, not the Disease

Shivank Khare (Y13)

One of the duties of a physician is to diagnose illnesses, injuries and administer treatments accordingly, to improve the quality of life of patients. However, in today's technologically advanced world, the latter is not a priority yet arguably the most important.

As medicine has evolved over time, physicians have got a better understanding on how to treat various illnesses but the pressure on physicians has also increased as more patients are admitted to hospital. To cope with the number of patients, physicians use test results such as blood tests, CT scans, X -rays etc. In doing so, doctors can eliminate patients who are supposedly thought not to be at severe risk. However, by talking with patients you get a better understanding from their point of view. e.g. someone with a dilemma as to whether they should undergo surgery or not. By talking with a patient, you can discuss the care needed post-operative surgery or perhaps the risks involved in surgery— alleviating the patient's worries and involving them in the decision. I have noticed this communication on many occasions on work experience as the urologist I was shadowing remarkably said, "By talking to the patients you get to see from their point of view and involve them in the decision – they feel less stressed as they contributed to the decision" [1].

There is rationale behind treating the disease as it leads to beneficial results. Treating someone with arrhythmia through anticoagulants may show a positive impact on their heartbeat as it may revert to a normal heart rate. However, social factors can have an influence on a patient's health. For instance, health inequality within society could mean individuals are less educated about their condition. Thus, it would be more beneficial to educate them on the steps to maintain their health in the long term rather than short term treatment as their condition could again deteriorate. However, the patient may also feel stressed as to whether they are at risk of getting a heart attack. Hence, caring for them can also be beneficial in the long term for their health.

Physicians converse with different types of patients from a spectrum of calm and composed individuals to patients suffering from depression or high anxiety. The latter are considered high risk patients as they are risk of dying and it is vital that their psychological beliefs need to be changed to reduce their suffering. A duty of a doctor is to empathise with a patient by listening to their fears, in order for the patient to feel more secure and to be more willing to discuss the urgent issues facing them. This enables the physician to deliver patient centred care which will be most effective in the treatment of a patient.

When physicians liaise with patients, they do so in accordance with the four pillars of medical ethics. I will discuss two of these that apply most in clinical communication. Patient autonomy enables the physicians to guide the patient to allow them to make an informed decision. There could be several different options leading to the same

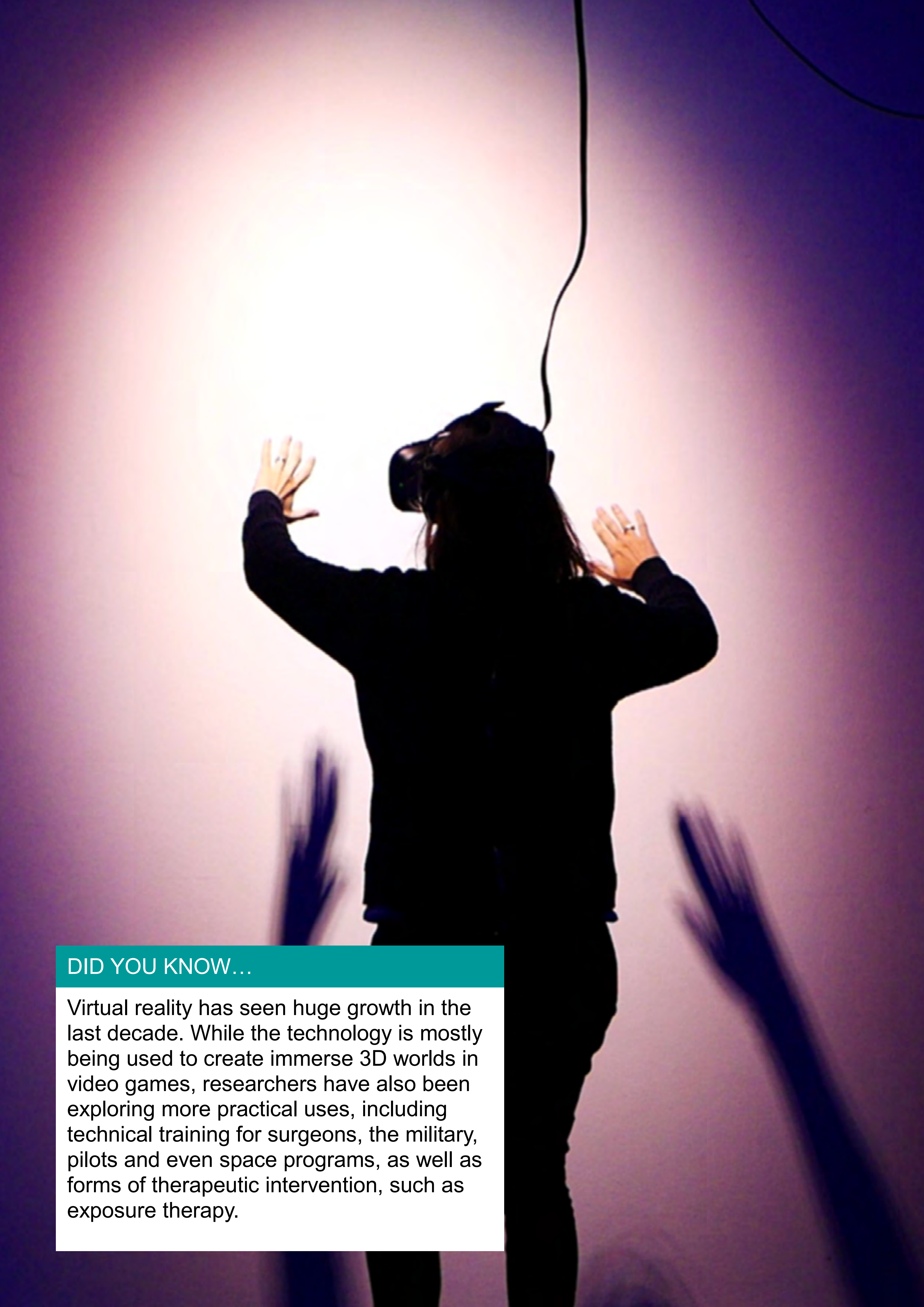
outcome for the patient. For instance, an obese individual could be advised to exercise more to reduce weight rather than immediately opt for weight loss surgery. By involving the patient into the decision, they are able to know the pros and cons of the situation and thus make a well-informed decision. This prevents the patient feeling concerned about the outcome of the operation nearer the date [2]. Choosing the non – surgical option is up to the patient having understood the situation.

Furthermore, beneficence is vital for helping the patient. By showing compassion to a patient, they would feel more at ease to make an informed decision. In the book ‘Do No Harm’ by Henry Marsh, a 96 year old patient had severe aortic stenosis (narrowing of the aortic valve opening). The physicians conversed with the patient – she wanted to stay at her home till her death rather than be treated at the nursing home and hence the physicians showed beneficence as they allowed her to stay at home with her family until she passed away. Through this example, we can see that the physicians “treated” the patient as she enjoyed her last years of life with her family (improved quality of life) rather than being separated from her family. This method of caring for the patient should be applied where possible to show compassion for the patient [5].

When treating a patient, most physicians should not only treat the desired corner of the canvas but to consider the entire picture. They have to consider the patient’s social, personal and psychological factors when addressing them. Through discussion in a calm manner with the patient, a doctor develops a good rapport. This enables the doctor to have a more certain diagnosis as the patient is more comfortable to discuss their symptoms [4] and divulge into more underlying information. Furthermore, due to the advancements of technology, physicians have had less time to spend with patients to get the individual care necessary for them. However, what matters is that physicians spend more time discussing with the patient as to what is important for them and for them to be involved so they feel valued [3].

Overall, a patient wants personalised care so that their worries can be addressed. Also, through the guidance of the physician they are educated on their condition in order to make an informed decision by outweighing the pros and cons. The duty of a doctor is for the patient to feel comfortable with the physician to establish a rapport for effective diagnosis. The role of a physician is to know the patient better to be able to suggest choices that would suit the patient. By doing this the patient would feel valued and hence their pain would alleviate as the physician is guiding them to the outcome best suited for them. The conversation between the patient and the physician should be welcoming and conversational rather than a meeting taking place. This can allow the physician to be able to address the worries facing the patient so that they can assist them to make a shared decision. By treating the disease, the physician would be preventing one problem but by educating the patient their quality of life would be improved for the rest of their life.

Edited by Divy Dayal



DID YOU KNOW…

Virtual reality has seen huge growth in the last decade. While the technology is mostly being used to create immerse 3D worlds in video games, researchers have also been exploring more practical uses, including technical training for surgeons, the military, pilots and even space programs, as well as forms of therapeutic intervention, such as exposure therapy.

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Game Development
Unity 2D **p29**

"I do not fear computers. I fear lack of them."

- **Isaac Asimov (Author of *I, Robot*)**

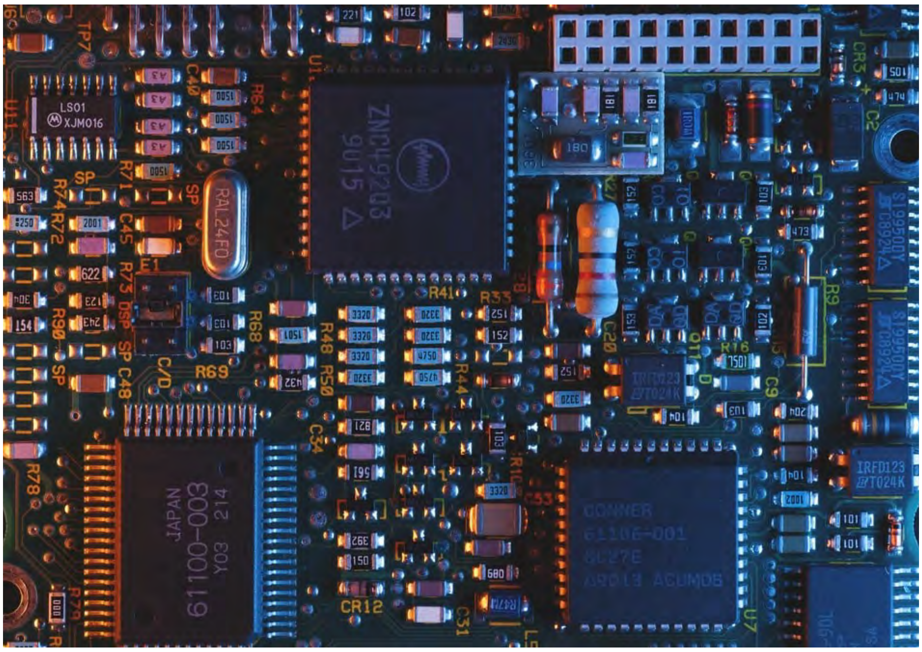


Image of a Central Processing Unit (CPU)

Computers

Exploring their anatomy and inner workings

David Kuc (Y13)

"People have grown so reliant upon them that if all of these devices were to suddenly disappear, the resulting pandemonium would likely cause more deaths than the recent coronavirus outbreak."

Computers have become extremely prevalent in modern day to day life. In a normal person's schedule, they are likely to use more than 5 computerized devices each day, from the machine which makes your coffee in the morning, to the circuitry in the trains you use, and the phone you carry, to the extent that there were more than 26 billion devices were connected to the internet in 2019. Due to this usage of devices, people have grown so reliant on them that if all of these devices were to suddenly disappear, the resulting pandemonium would likely cause more deaths than the recent coronavirus outbreak.

However, despite how common they are, very few people actually understand how they work, and what causes them to do what they do. Therefore in this article, I will be describing how computers perform their tasks on a theoretical level.

The Central Processing Unit

The CPU is the core of the computer. It receives instructions and executes them. Its role within the computer is comparable to the brain of a human.

The main components used within computers are transistors. These are small electrical components which produce only produce a current if they receive an input and a check current.

Therefore transistors can be used in simple circuits, as demonstrated below (Figure 1), to produce various logic gates.

If you layer up various gates in specific patterns you can create larger circuits capable of executing various commands and responding to specific inputs, e.g. with an combination of 'xor' (an 'and' circuit using the results form a 'nand' circuit and an 'or' circuit) and 'and' gates you can create a binary addition circuit capable of adding 2 bits together. Furthermore, if you were to layer the bit addition circuits together in a pyramid structure, you could create a circuit capable of multibit addition. Likewise, binary subtraction can be performed through the use of 2 addition circuits and a not circuit. Therefore, you can build a complex piece of architecture capable of adding and subtracting numbers, among other things. The result of this is the CPU.

The Storage and Memory

For computer scientists, storage and memory are two distinct things. Storage is non-volatile, which means that it retains its

Figure 2: Magnetic Hard Disk

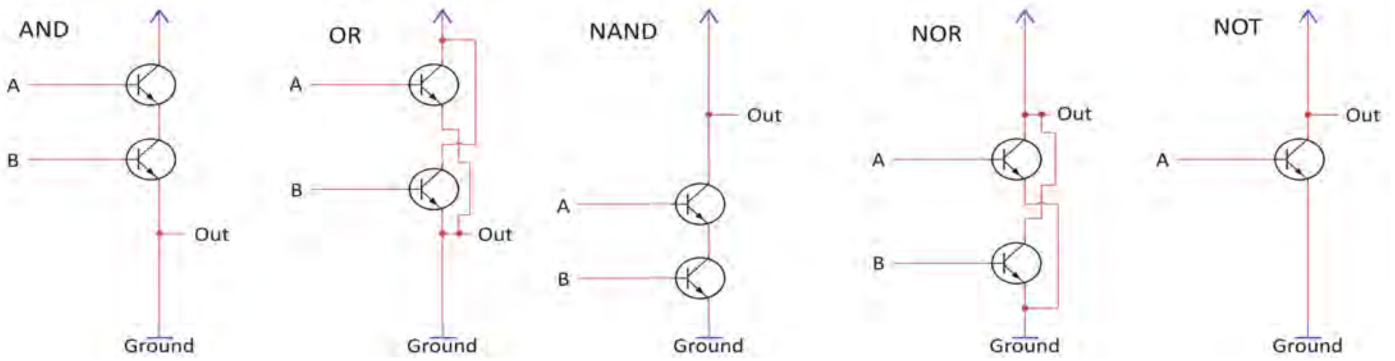


Figure 1 - Transistors used to make logic gates

data even when power is not supplied, while memory is volatile so the computer will lose the data stored within when power is lost. Storage is therefore used to save data, while memory is used to store currently running applications and programs on the computer and it sometimes also stores recent or frequently accessed programs if there is enough space. This is because memory is usually a lot faster than storage, and it is also far more durable.

However, a computer doesn't just run programs, but it stores them as well. When the computer is off, all of the programs are stored in storage. The most common forms of storage are the HDD and SSD.

The hard disk drive uses magnetic plates which can be moved via magnetism to store data, then when the data is collected, a current is run through the section with the plate, and if the plate is in position, then the current is transferred through, if not, then the current does not pass through. Thereby, each plate can store a single bit. The solid state drive uses floating gate transistors to store electrical charge within a silicon chip. These chips are stacked in a grid allow a lot of data to be stored. SSD storage is therefore a lot faster and smaller than HDD memory, but due to the relative novelty of the concept and its greater complexity, SSDs are more expensive and are harder to produce. Furthermore, solid state memory is less durable, and will wear down sooner.

Memory comes in 2 main types DRAM (RAM) and SRAM (cache). In DRAM, each memory cell consists of a transistor and capacitor. The capacitor stores charges, but frequently needs to be refreshed as it loses energy. For cache, each memory cell consists of 6 interlocking transistors, it is therefore faster, though it uses up 3x as much space as dynamic ram and is a lot more expensive.

Et Cetera

With just the prior components, you wouldn't be able to build a working device, there are still 2 more things you need, the power supply, and the motherboard. The power supply is an adaptor which converts the AC input current into a DC output that can be used by the computer components, and the motherboard is a large circuit board which connects the components together. If you're planning to render videos or games, then you can also get a graphical processing unit, which is like the aforementioned CPU, except it is specifically designed for complex mathematical equations and generating video output (it even has its own form of memory called VRAM).

Peripherals

Now you have your computer, but sadly you still can't use it. In order to do so, you would need to be able to interact with it and have it respond. Therefore you need peripherals. There are output devices such as monitors (screens) and speakers, and input devices such as mice, keyboards and joysticks.

Edited by Utkarsh Sinha

GIFS

Why They Aren't As Common As You Think

Michael Lowe (Y13)

What is a GIF?

GIF stands for Graphics Interchange Format. It is a standard protocol for the storage of the data needed to produce an image. This means that a GIF is a type of image that has been stored in a particular way.

What makes the GIF format special is that it can be used to store animations, as well as regular still images. A single GIF file can hold the information for a short sequence of images that should be played in succession.

While regular GIF images are not as common as more optimised and compressible image formats like PNG and JPG, animated GIFs seem to be everywhere.

Despite its popularity, though, the format has a couple of issues.

Problems

The most visually obvious problem is the limited number of colours (bit depth). While a typical PNG or JPG image can

A GIF with a limited number of colours, which makes the dithering effect easy to spot.

DID YOU KNOW…

In October 1991, the term "surfing the internet" was popularised by the Internet Service Provider CERFnet in the comic book "The Adventures of Captain Internet and CERF Boy" .

store $256^3 = 16777216$ different possible colours for each pixel, a GIF image can usually only store 256. This means that GIFs will often look cartoony, with blocks of colours and limited detail.

To compensate, a technique known as dithering is often used, where dots of colours are interwoven with each other, producing a speckly effect that is identifiable in almost every GIF image (if you zoom in close enough). Dithering can help blend colours together, preventing "banding", where bands of colours are visible. There are methods to fix the limited number of colours, but, as I am about to discuss, they can result in huge file sizes.

The biggest issue with the GIF format is the large amount of storage space required: the median GIF image (in webpages collected by HTTP Archive) takes about 2.5x as much data to store a JPG image of the same dimensions. Also, while the larger file sizes are a drawback for still images, animated GIFs are especially inefficient at storing the information. While video formats such as MP4 track changes in pixels, saving a significant amount of space for long videos, GIFs are not well designed for video, and, as a result, a lot of space is wasted. MP4 files "require up to 95% less disk space for the same image quality" (Telegram, 2016).

Mainly because of the large file sizes, GIFs aren't as common of you might think. Twitter, Reddit, Facebook, Giphy (now owned by Facebook), Snapchat, Imgur (and other social networks where GIF-sharing plays a prominent role) all convert GIFs into MP4 videos. This allows users to experience faster speeds as less data needs to be downloaded onto their device.

That being said, in many of these sites—including Giphy, Tenor and Imgur—users can upload and download the animations as GIFs too.

Why are GIFs so popular if there are better alternatives?

The main reason GIFs are still used so much is due how easy they are to use. They are widely supported: every major browser and messaging app supports them. The reason that GIFs have so much support is that they made it into early browsers for the world wide web, as the standard was easy to implement, due to the format being based off the very basic bitmap (BMP) format. Ever since then, GIFs have made their way into all sorts of applications.

Even Microsoft Word, which I am typing this article on, supports animated gifs (although the PDFs don't, so you won't be able to see the person dancing in the image on the right).

Also, animated GIFs "just work" in many places where videos don't make sense. It's a simple way for users to have looping videos with no sound, without the need for a full-blown video player.

The Two Types of GIF

There are really two definitions of a GIF. First, there is the technical one: Graphics Interchange Format, a standard image format, invented in 1987, which has the ability to store low-quality animations and still images.

But increasingly there is another definition of the word: a "gif" being a short, auto-playing, silent, looped video, especially a reaction. This second meaning of the word is probably the one you are more familiar with: when you send a friend a picture of SpongeBob Square Pants, you don't care how the information is stored; you only care that it works.

So, while the animated GIF file format is—quite rightly—seeing a decline in its use in large websites and applications, GIF-style videos aren't going anywhere soon.

Edited by Utkarsh Sinha

Game Development in Unity 2D- Introducing the Inspector

By David Lin (Y13)

As we now have more and more video games available in our society today, the demand for games and jobs for games has risen due to the enjoyment that people get from them. This article will provide you with some of the information you may need to know in order to make your own game in Unity (the code that is used here is C#), which is a free gaming software.

The inspector is very important in allowing your in-game objects to be able to move and carry out actions that allow your game to function. When you click on an object that is in your game, the following window should appear on the right of

your interface. This window is the inspector screen:

Transform

The transform section here allows you to position the centre of your image to where you want it to be. Rotation allows you to angle the image in any assigned plane, and scale allows you to adjust the size of the image.

Sprite Renderer

This tells you about all the information about your 'Sprite'. In the case that you dragged in an incorrect sprite or you want to change image used during rendering, you would change the Sprite section of the Sprite Renderer by selecting a different Sprite or through the use of code.

Most of the other sections in the Sprite Renderer are usually left untouched. However, a very important thing that should be addressed is the sorting layer. The sorting layer allows you to change what layer the game object is placed in. In the case that you want the Sprite to be in front of another game object, you would have to create another sorting layer below the current layer and select it.

If you want the game objects to be on the same layer but want to set a render priority, change the order in layer to either a negative number (rendered first) or a positive number (this overlaps smaller numbers).

Animator

The animator hold all the animations that you have put on the sprite and usually the public variables are left untouched for very basic games.

Add Component

This here allows you to add many of the interactive components, which allows you to control collision, coding and essentially everything in your game. Since there isn't much space left, I won't go into much detail about this until next issue. Some of the most basic components include: BoxCollider2D, which allows you to add a collision box on your game object, CircleCollider2D, which is a collision circle placed on the game object. It should be noted that the playable character(s) in your game should use a CircleCollider2D and not a BoxCollider2D. The most essential component that you should always have is the Rigidbody2D component, which tells the game system that your game object has a body and allows other components to function. Without it, movements won't happen.

Edited by David Kuc

DID YOU KNOW…

Standing at 309 metres, and with 27 floors, the Shard is the tallest building in the UK. Construction began in 2009 and wasn't completed for another four years. A total of five cranes were used during construction, four of which "jumped" with the building as it grew.

> *"Man must rise above the Earth—to the top of the atmosphere and beyond—for only thus will he fully understand the world in which he lives."*
>
> \- **Socrates**

Lockheed SR-71 Blackbird—a long-range, high-altitude, Mach 3+ strategic reconnaissance aircraft

J-58: The Heart of the Blackbird

A detailed examination into its structure

Ray Wang (Y13)

It is hard to put into words the engineering marvel that is the SR-71. As a reconnaissance aircraft, it cruised faster than three times the speed of sound, flying high above the enemy to gather valuable photographic intelligence. It was its incredible performance that meant the SR-71 was untouchable by its enemies, despite carrying no weapons. Even though it was designed during the early 1960s, the SR-71 still holds the record for the fastest air breathing manned aircraft to this day.

Behind all of this was an ingeniously engineered propulsion system, able to remain functional and relatively efficient at airspeeds ranging from Mach 0 to 3.2 (Mach 1 being the speed of sound). The fundamental problem was that the type of jet engine required for cruising at supersonic speeds of Mach 3.2 for prolonged periods of time was completely different to the engine design that would be required for subsonic flight. This along with the whole host of issues concerning fuel efficiency, shockwaves and cooling when operating at such high speeds fell to the engineers at Skunk Works and Pratt & Whitney to solve.

But first we need to understand how a jet engine works, so let's simplify things a bit and consider a balloon which has high pressure air inside compared to its surroundings (Fig 1). We've all seen a blown up and untied balloon whizz around a room when let go but why does this happen?

Newton's Third Law of Motion, states that for every action there is an equal and opposite reaction. In the case of our balloon, the force of the high pressure air escaping out of the opening is the "action" force which in turns causes an equal and opposite "reaction" force acting on the balloon that pushes the it forwards. Another way to consider this is in terms of conservation of momentum. As the expelled air has a momentum (equal to its mass × velocity) backwards, the balloon must have an equal momentum forwards (since the balloon also has mass, it must therefore also have a forwards velocity) so that total momentum is conserved.

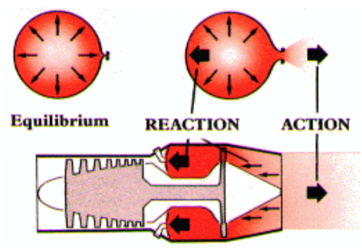


Figure 1 Action reaction force pairs in a balloon and a jet engine

A jet engine produces thrust though exactly the same principles but the exhaust gases are created through a somewhat different process. Any jet engine has four stages of intake, compression, combustion and exhaust. In the intake stage, the air enters the engine at a relatively low pressure. This air must then be compressed before the combustion stage where the high pressure airstream is then mixed with a fuel and then ignited, triggering the exothermic chemical reaction of combustion. The negative enthalpy change of this reaction results in the release of thermal energy that subsequently causes gases to heat up and expand. These hot gases will then exit the back of the jet engine much like on the balloon, generating thrust to push the engine and the aircraft forward.

But why must this air be compressed before it is combusted? It's all about increasing the energy potential of this air as this directly affects the magnitude of the thrust that can be produced. Compressed air, as a high pressure gas, will already naturally want to expand so compressed air will store some additional potential energy. Compressed air mixed with fuel is also easier to ignite and will burn for longer, since there is a greater density of oxygen. Oxygen is a reactant in the combustion process so having a higher density of oxygen allows more reactions to take place in the combustion chamber, leading to a greater increase in the thermal energy transferred to the air. Subsequently, the more energetic exhaust gases will move faster out of the engine, in turn generating a greater thrust force on the engine. Ultimately this leads to a vast increase in the energy potential of the air, allowing the combustion stage to make a much more effective use of the fuel, resulting in a far greater thrust force being produced while using the same volume of fuel.

Now we can take a look at a couple of different types of jet engines. For subsonic flight, the ideal engine would be a turbojet. In this type of jet engine, air is drawn into the turbojet through a fan at the front of the engine. Air compression is achieved as the airflow is passed through a series of sets of progressively smaller fan blades that compress the air to a higher pressure. Just before the exhaust gases are ejected, they pass through a turbine that is connected to the fan and compressor via a shaft which turns the fan and compressor to actively draw in and compress more air, allowing the cycle to continue.

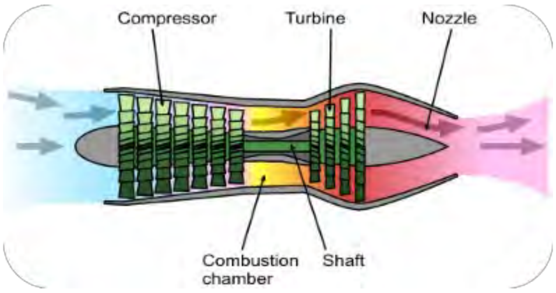


Figure 2 A turbojet engine

However, for an aircraft to fly faster than the speed of sound (where Mach Number (M) > 1), it must be able to overcome a sharp increase in drag as the aircraft transitions from subsonic to supersonic, a speed range known as the transonic region. To do this, aircraft need to generate significantly more thrust and for this aircraft typically use an afterburner, attached to the nozzle of the jet engine. An afterburner works by injecting fuel directly into the stream of hot exhaust gases to react with and use up any oxygen that may be left over, generating even more thrust. While afterburners allow for massive increases to the thrust, they are typically only used for short bursts of acceleration as they are highly inefficient, requiring huge increases in fuel consumption for the increased thrust force. This poses a problem when designing an aircraft to travel at very high speeds. The only way to achieve those speed during cruise using a turbojet is to use an afterburner continuously with it, but that then makes the aircraft so fuel thirsty that its range is shrunk to the point where such an aircraft becomes impractical for any reconnaissance mission.

In order for an air breathing aircraft to cruise at speeds as high as Mach 3, the type of engine you really want is a ramjet. While a ramjet uses the same conceptual stages of intake, compression, combustion and exhaust as a turbojet, a ramjet instead relies on ram pressure to compress the air as opposed to a series of compressor blades found in a turbojet. Simply put, ram pressure is the pressure that occurs as an aircraft rams itself through the air at high speeds.

A ramjet must ensure that the low pressure supersonic airflow entering the engine is converted to high pressure subsonic airflow before the combustion stage. Supersonic air flow must be slowed down to subsonic since jet engines typically cannot digest supersonic air flows since when air flows faster than the speed of sound. With supersonic airflow, pressure waves will bunch up and cause shockwaves to form inside the engine, disturbing the smooth uniform flow of air, which is vital to the operation of an engine. Like in the turbojet, compression of the air is vital to increase the energy potential of this air and subsequently the thrust that the engine produces.

The first stages of the ramjet must therefore both decelerate and compress the airflow as it enters the engine. The beauty is that when it comes to fluid flow, decreasing speed and increasing pressure come hand in hand meaning that a ramjet only has to decelerate the airflow and the pressure increase will occur naturally, a phenomenon explained by Bernoulli's principle. Since air cannot be stored in the system, the volume of air entering is equal to the volume of air leaving. If the volume of air entering the system is at a high speed and it leaves the system at a lower speed, this must be compensated for with a higher pressure so that the same amount of air passes through and none of it is held in the system. A side effect of the pressure increase is that the temperature of the air will also increase, further increasing the energy potential of the air. From then on, the remaining two stages are identical to a turbojet engine: the air is mixed with fuel before being ignited in the combustion chamber where it expands and accelerates as exhaust generating thrust. With far fewer moving parts, a ramjet can operate (and is far more efficient) at airspeeds far greater than a turbojet would be able to withstand.

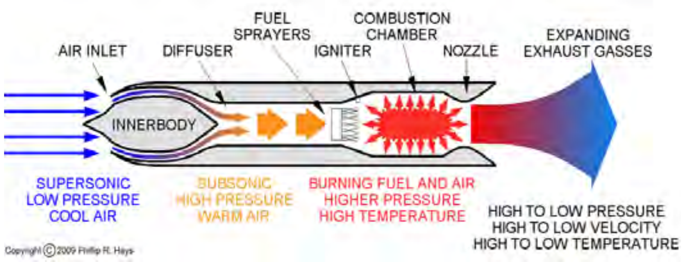


Figure 3 A ramjet engine

So how exactly does a ramjet manage to slow down the oncoming airflow without having any moving parts? To understand this mechanism, we need to delve a little deeper into the world of shockwaves. When an object is flying through air, at low speeds well below Mach 1, it actually meets relatively low resistance, as if the air ahead of the object knows that the object is coming and moves out of the way. While this may seem a little strange but this is in fact precisely what happens. Air molecules collide with the leading edges of the aircraft, causing the molecules to bounce back off and rebound in the opposite direction, travelling forwards at a speed that is faster than the aircraft is moving forwards at. This creates an area of high pressure waves in front of the aircraft's leading surfaces which interacts with oncoming air to smoothly push it aside of the oncoming aircraft, reducing its resistance.

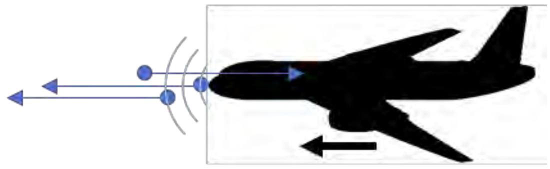


Figure 4 Air molecules interacting with a subsonic aircraft and pressure waves formed

A pressure wave in air (also a sound wave) is really just air molecules bumping into each other to transfer energy from one molecule to another. These pressure waves always travel through the air at the speed of sound (Mach 1) and this is the maximum speed that a pressure wave can travel through air. However, this is certainly not the fastest speed that an aircraft can go. As an aircraft nears and exceeds the sound barrier, the airflow around it becomes rather interesting. Let's consider the three examples in Fig 5.

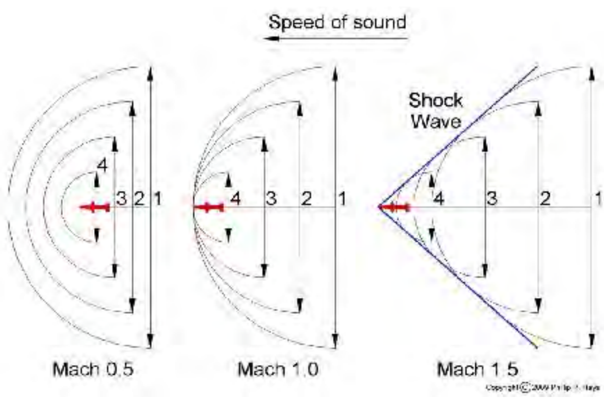


Figure 5 Pressure waves around aircraft at various speeds

The aircraft (shown in red in each diagram) on the left is moving at half the speed of sound. Therefore the pressure waves dissipated from the surface of the aircraft are moving at twice the speed of the aircraft itself. In this case, each wave races ahead of the aircraft and they are compressed into a region of high pressure in front of the aircraft where pressure waves are closer together, which can also be explained with the widely known doppler effect.

The aircraft in the middle is moving at exactly the speed of sound. This means that the pressure waves can no longer move ahead of the aircraft so instead the waves are all compressed at a point in front of the leading edge of the aircraft.

The aircraft on the right is moving beyond the speed of sound so now the pressure waves cannot move as fast as the aircraft meaning that the aircraft races ahead of the pressure waves. Consequently, all the pressure waves moving outwards from the aircraft combine to make one high pressure conical shock wave. If the aircraft is moving fast enough the shockwave will attach itself to a sharp leading edge or point of the aircraft forming an oblique shockwave, with the angle of at the vertex of the conical shockwave narrowing as the aircraft flies faster.

There is now no forewarning to the air about the oncoming aircraft's presence so the air in front of the aircraft cannot be smoothly moved out of the way of the aircrafts path. As an aircraft flies supersonically, the shockwave moves with the aircraft. We can instead consider the aircraft and its shockwave to be stationary while the airflow around it is moving. This means that relative to the shockwave, the airflow is supersonic before it encounters the shockwave. When oncoming airflow hits the shockwave, there is an almost instantaneous deceleration of the airflow. This is the key which unlocks the door to how ramjets work: shockwaves decelerate airflow.

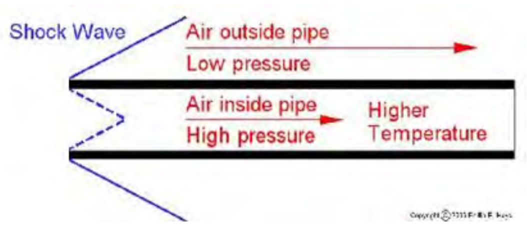


Figure 6 A hollow tube experiencing supersonic airflow

Now let's simplify the ramjet to just a tube, moving supersonically through air, oblique shockwaves will form at the leading edges of the tube as shown in Fig 6. These shockwaves covering the opening to the tube will then decelerate the airflow entering the tube and consequently increasing the pressure and temperature inside the tube.

Our tube simplification is slightly misleading though as it appears that we have created a perpetual motion machine. It shouldn't come as a surprise that hollow tubes in fact don't magically fly through the air at supersonic speeds because the force of that drag the tube would experience at those speeds is far greater than the thrust that the tube could produce from the high pressure heated gases inside. A ramjet essentially places a combustion chamber inside this tube to heat the gases further so that the thrust does exceed the drag, propelling the engine forward.

By now you may have noticed the flaw of a ramjet is that it needs a ram pressure to work, and therefore requires forward movement in order to achieve suitable compression of air for the combustion chamber. Unlike a turbojet which actively draws in and compresses air, a ramjet achieves compression through passive means by utilising the geometry of the air inlet and the forward motion of the aircraft and therefore cannot start from low speeds and zero, meaning that ramjet powered aircraft (typically missiles) must be brought up to speed by and then launched from a mothership aircraft or must incorporate a secondary propulsion system.

The ingenuity of engineers at Pratt & Whitney and Skunk Works was to combine a ramjet with a turbojet into a turboramjet for efficient operations at both high and low speeds. This innovative new propulsion system consisted of the sophisticated air inlet followed by the J58 engine itself with an afterburner at the rear, all enclosed within the engine casing known as the nacelle.

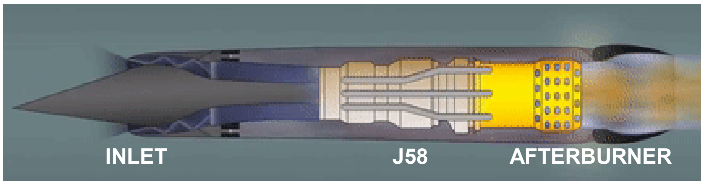


Figure 7 Basic composition of the SR-71 engine nacelle

At speeds below Mach 2, the system worked just like any other afterburning turbojet engine, explained earlier in the article. However, what really sets the J58 apart from other engines is the six bypass tubes shown in red in Fig 8.

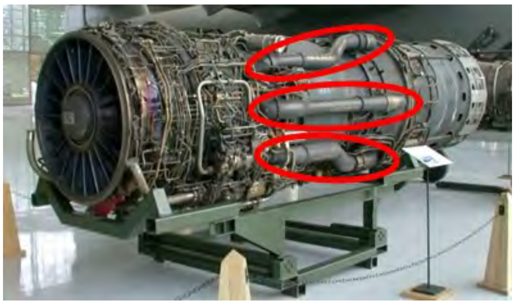


Figure 8 Bypass tubes on a J58

These bypass tubes opened at speeds greater than Mach 2.2 and funnelled high pressure air from the early stages of the compressor directly into the afterburner, bypassing the later compression and combustion stages within the J58 and injecting this high pressure air straight into the afterburner which now acts more like the combustion stage. By doing this the propulsion system behaves more like a ramjet with minimal active compression as opposed to an afterburning turbojet. This means that the afterburner now works at a far higher efficiency as it is being fed highly oxygen rich compressed air as opposed to just exhaust gases which containing minimal leftover oxygen having already passing through the combustion stage of the turbojet. It was this ability to transition from a turbojet to a ramjet for high speed flight that allowed for the SR-71 to not only to reach but to comfortably cruise at speeds of which would've made a conventional turbojet melt while still flying relatively efficiently.

To understand this, let's take a look at MiG 25, the only aircraft to ever come close to the speed of the SR-71. Unlike the SR-71, the MiG -25 was rather crudely powered by enormous conventional afterburning turbojets (as you can see by the size of the afterburners and intakes in Fig 9) which allowed the aircraft to cruise at only Mach 2.25. The MiG 25's maximum design speed was Mach 2.83 which it was only able to sustain in 5 minute bursts due to the risk of overheating. The crazy thing is that the MiG 25 could actually be pushed to Mach 3.2 but this would cause so much damage to its engines that they would then have to be completely replaced upon landing. The MiG 25 also had an incredibly low fuel efficiency. These issues were resolved in the SR-71 with the use of a hybrid turboramjet design, instead of trying to push the limits of a turbojet like the MiG 25 did.

Figure 9 The MiG 25

The design of the air inlet on the SR-71 plays a crucial role in the operation of the propulsion system. From earlier in the article, we know that the job of the inlet leading to a jet engine on a supersonic aircraft is to slow the supersonic airflow to subsonic before it enters the engine so that shockwaves don't form inside. In a ramjet this also serves the purpose of compressing the airflow.

Like with the hollow tube explored earlier, the inlet of the SR-71 achieves this deceleration and pressurisation of airflow by creating shockwaves at the inlet by using the shapes of the leading edges. One of the most noticeable things about the SR-71 is the cone protruding out of the front of each engine. This is known as the centerbody or the translating spike and when the aircraft goes supersonic, an oblique shockwave forms on this centerbody spike which moves the pressure of the leading shockwave away from the engine inlet, giving the engine the best airflow. The other shockwaves we can see in Fig 10, initially form from the cowl lip in the same way that shockwaves form at the leading edges of a hollow tube. However, unlike the completely hollow tube we explored earlier, there is now the centerbody inside the inlet so that the shockwave coming off the cowl lip is reflected the back and forth between the centerbody and cowling in a zigzag series of reflected shockwaves ending with the terminal shock which is a normal shockwave (forming perpendicular to the centerbody surface) acting as the final shockwave to slow the air to subsonic speeds that the engine can handle. As high speed air flows into the inlet, it encounters this shockwave series, where each shockwave works to decelerate the incoming airflow, increasing its temperature and pressure.

As the speed of the aircraft increases, the angle between the shockwave and the cowl lip narrows, resulting in the position of the terminal shockwave moving further back into the inlet. When the aircraft is travelling at Mach 1.6, the position of the terminal shockwave is optimised since this minimises the energy lost due to drag as air flows over the shockwave, leading to the maximum possible increase in air pressure. To maintain the terminal shockwave at this optimal position instead of it moving further back as the speed increases past Mach 1.6, the centerbody retracts into the inlet incrementally at 41mm per 0.1 increase in Mach number past Mach 1.6. Doing this changes the geometry of the inlet, widening the air stream capture area and narrowing the throat area so that the reflected shocks still end up with the terminal shockwave in the optimal position.

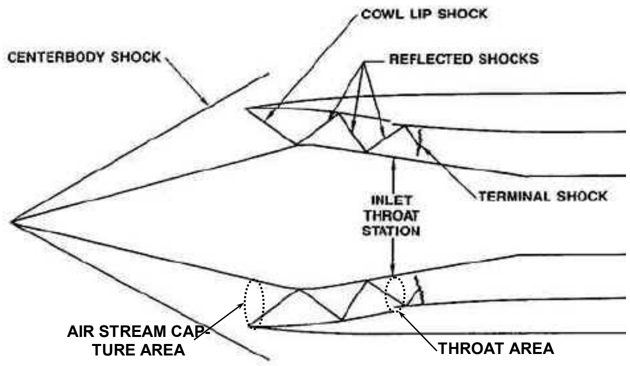


Figure 10 Shockwaves formed in the inlet

When the aircraft reached its cruise speed of Mach 3.2, the centerbody would have fully retracted back around 66cm which would position the centerbody shockwave right on the edge of the cowl lip increasing the air-stream-capture area by 112% and reducing the throat area by 54%. This efficient arrangement at Mach 3.2 meant that the inlet was able to deliver the vast majority of the compression at a ratio of 39:1 while the compressor turbines added an additional compression of 1.6:1.

In the case that the centerbody shockwave exceeded the cowl lip, this would result in an unstart where the inlet would suddenly be filled with more air than it could handle, dramatically increasing the air pressure inside forcing the terminal shockwave to be belched out of the inlet.

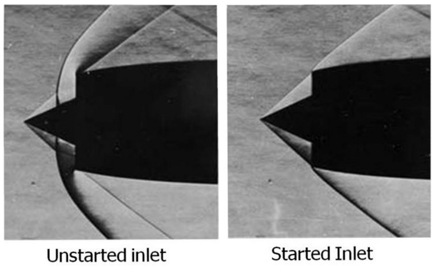


Figure 11 Shockwaves at a started inlet vs an unstarted inlet

Another problem the system had to handle was how the engine was going to be kept from overheating during all speeds of flight. To do this, engineers designed a system to continuously pass cool air through a bypass area around the J58 engine in the nacelle body, again catering for vastly different speeds. Positioned inside the inlet cowl (Fig 12) is a cowl bleed opening which funnels some of the incoming air into the bypass area and through shock traps that reduce the air speed to subsonic. This airflow is then guided through the nacelle body and around the J58 engine, cooling it down before being drawn out by the rapid exhaust gases flowing at the rear afterburner. This also serves a secondary purpose of adding even more oxygen into the afterburner for combustion, further increasing the thrust that the engine could produce. The airflow into the inlet at higher speeds creates a sufficient airflow around the engine to cool it but at speeds lower than Mach 0.5, there is not enough air coming into the inlet for cooling so more air is drawn into the nacelle through secondary suck in doors that are located in the middle of the nacelle. These doors remain closed for the majority of flight when speed is above Mach 0.5.

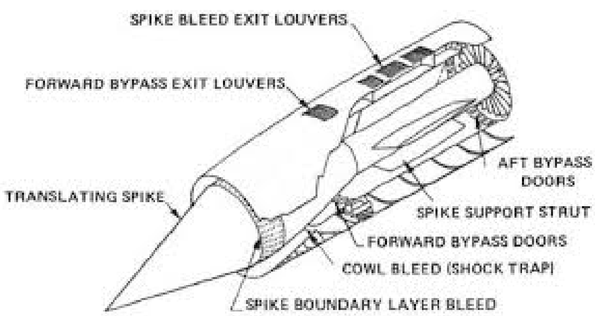


Figure 12 Key parts of the forward section of the nacelle

Now let's take a look at some of the finer details that work towards the smooth operation of this propulsion system. The spike bleed system (Fig 13), which connects a set of slots on the translating spike collectively known as the spike bleed, through the hollow centerbody and up one of the four spike support struts, up to the spike bleed exit louvers, on the exterior of the nacelle. At high speeds, these holes wick away the boundary layer that forms on the translating spike. The boundary layer is a layer of slow moving turbulent air that clings to the surface of the centerbody. By bleeding this away to the exterior, this frees up a greater air stream capture area for high energy fast moving air, improving the efficiency of the system. This centerbody bleed system actually serves another purpose: the air can actually flow the other way, from the spike bleed exit louvers into the spike bleed, allowing the engine to pull additional air into the inlet when it is needed at low speeds.

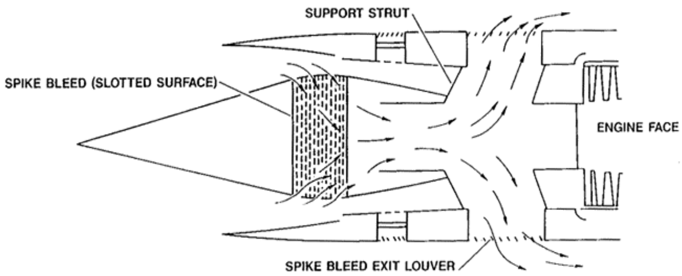


Figure 13 Spike (centerbody) bleed system

Aside from the centerbody, there are a couple of more sophisticated bypass systems designed to fine tune to pressure inside the inlet if it is too high, keeping the normal shockwave exactly in its optimal position. Firstly, there are the forward bypass doors which are controlled by an onboard computer and are opened if the pressure in the inlet is too high. This reduces the pressure inside the inlet by sending some of the air directly out of the aircraft. Additionally there are the aft bypass doors controlled by the pilot which can also reduce pressure in the inlet but instead of sending the air outside the aircraft, these doors route some of the air into the cooling bypass area around the engine and out of the afterburner, providing additional cooling to the engine as a side effect.

All these mechanisms from the conceptual to the fine details were harmoniously brought together to provide the SR-71 with a truly ground-breaking propulsion system allowing the SR-71 to perform its unique duty. The insane thing is that this propulsion system actually had far more to give and could've provided enough thrust to push the aircraft to speeds as high as Mach 5. What really limited the top speed was fuel efficiency and the titanium that the aircraft itself was made of which would literally melt if the aircraft was to fly that fast. An incredible combination of ingenious engineering solutions married together to create a real marvel of engineering.

Edited by Utkarsh Sinha

Volkswagen's W-Engines: An Engineering Marvel?

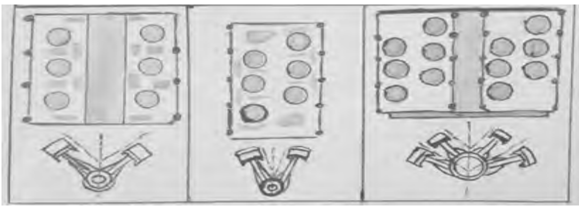
Navaneeth Krishna Kanakkaparambil (Y13)

The German patent number 37435 was the number for what could arguably be known as one of mankind's greatest inventions: the automobile. Ever since Karl Benz built the world's first car in 1885, the world of automotive engineering has grown immensely. People's demands, the ever-changing global economy, and the desire of car manufacturers to produce the best machines have all contributed to the rapid evolution of car design. Speed, safety, and aesthetics have all changed. The mechanical components have also undergone drastic changes to accommodate the demands of the modern consumer. The engines are a component that has undergone the most extensive developments. Over the years, we have seen many different engine types. We have in-line engines, the boxer engines, the V engines, and rotary engines. Despite the variety of options available, few powertrains can aspire to reaching the heights of the folklore and fervour around W engines.

Early versions of W engines were employed in aircrafts such as *'The Napier Lion'* which used a three-bank design of a 24-litre W12 engine. It could produce almost 900 horsepower. This is an impressive figure, even by modern standards. The engine's ability to produce such high levels of propulsion meant that it was used in military and racing aeroplanes whilst also being used to break land speed records with the Napier-Campbell Blue Bird. However, despite the power produced, W-engines were rarely used in conventional cars due to their size and weight. As time went on, the desire for higher speed and performance grew. Manufacturers tried everything to earn the title of being the producers of the fastest cars. This greed for speed even attracted the attention of the 'people's car' company: Volkswagen (VW). The Volkswagen group are no strangers to producing high-performance supercars with the group consisting of Audi, Bentley, Porsche, Lamborghini, and Bugatti (Uccello ,2019). Despite their reputation for creating economical hatchbacks through their main marque, the Volkswagen group had a vast array of resources to create machines that were symbols of excellence.

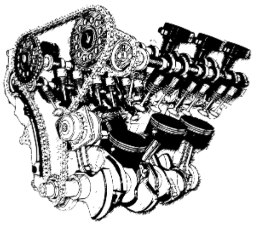
BENTLEY BUGATTI PORSCHE

W engines consist of two VR-engines positioned with a 72-degree V angle. VR engines are very similar to V-engines with the main difference being the smaller V angle between the cylinders. In V-engines the cylinders are arranged with a V angle that ranges from 60 to 120 degrees. This meant they were relatively short compared with inline engines. However, due to the large V angle, the V-engines are much wider and, have two separate cylinder heads, which requires a more complex design and a larger engine block. To reduce the size of the engine while maintaining power and torque figures, Volkswagen developed VR engines. The cylinders are offset at an angle of 15 degrees and accommodated in a compact engine block. The layout has the additional benefit of requiring only one-cylinder head which reduces weight and adding to the performance improvements. This combination of space efficiency and high-power output made the VR engine the ideal template for W engines, which would go on to produce some of the most iconic road vehicles of all time.



Left to Right—V, VR, and W engines

Throughout the years 1997 to 2001, VW produced multiple W12 concept cars. In 1998, they developed the W18 Bugatti Chiron concept and a W16 Bentley

Engine Fact File	Benefits and Drawbacks
Inline Engines: ***These are engines that have their cylinder banks in one line.***	
	Inline engines are known for being smooth. For example, an inline 4 engine will have 2 pistons going up at the same time as 2 going down, resulting in good engine balancing and lower vibrations which result in a smooth engine. They are compact and lightweight, resulting in better fuels efficiency and ease of fit in small cars. (Slideshare, 2020). However, as the number of cylinders increases, it becomes harder to fit an inline into a car as they get longer. They have a high centre of gravity which can lead to unwanted vibrations at high speeds. (Jefferson, 2020).
V Engines: ***These are engines that have cylinders arranged in two separate banks on a 'V angle' that can range from 60 – 120.***	
	It is important to note that the angle varies between manufacturers and this can provide different advantages and disadvantages. Nonetheless, V engines are compact and can pack in more cylinders than an inline engine of the same dimensions. Therefore, they are more powerful. V engines like the V8 are some of the smoothest in the world as they are naturally balanced and have a low centre of gravity. On the contrary, they have more moving parts which can lead to higher maintenance costs and increased complexity. Poorly aligned engines can be unbalanced and lead to numerous unwanted stress and vibrations (Jefferson, 2020).
W engines: ***Engines that have Two VR style cylinder banks aligned in a V configuration***	
	This engine packs many cylinders in a relatively more compact space compared to V and inline engines and can be perfect for high performance cars. It can also have a lighter and more compact design which can allow high performance cars to be more aerodynamic. The ability to produce massive amounts of power allows a maximisation of power-to-weight ratios. However, they are incredibly complex and difficult to maintain. This can lead to higher costs and difficulty for repairs. They can also be heavy, and this could lead to low fuel economy. (Slideshare, 2020).

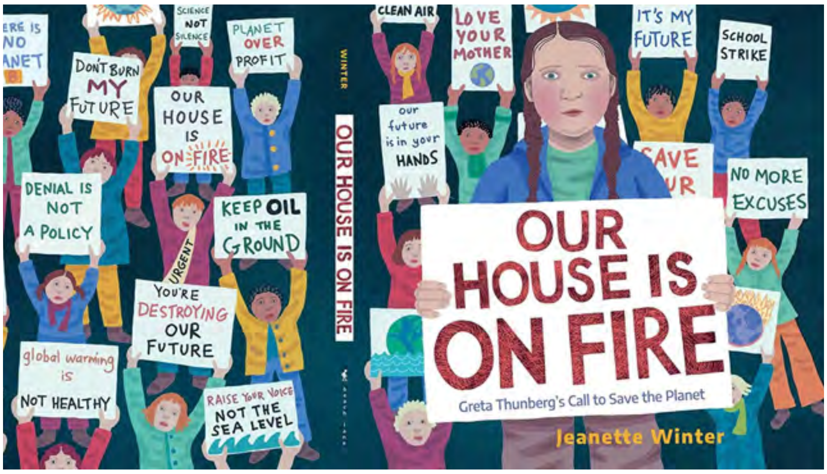
Hunauderies concept. The former would go to become one of the fastest and most complex machines to ever be built by the automotive world as the Bugatti Veyron. Three years later Volkswagen came up with the Nardo W12 which, as the name suggests, used a W12 engine. Critics of the W12 pointed out the lack of smoothness compared to its more popular counterpart, the V12. This was mainly because of the W12 having many moving parts and being less balanced than the V12. However, the aerodynamically friendly compactness of the W12 made it ideal for high for high-performance vehicles by maximising power-to-weight ratio and allowing for more focus on aerodynamics. Unsurprisingly then the Nardo had a scintillating 0-60 mph time of 3.5 seconds and broke multiple records. One notable record was when it managed to around the 7.8-mile Nardo bowl for 24 hours with an average speed of 200.6 mph while covering about 4900 miles.

However, the W-engine's brilliance did not end there. In 2005, Volkswagen's Bugatti released the Bugatti Veyron 16.4. It had an 8.0 litre quad turbocharged W16 engine with 987 BHP and gave it a top speed of 253 mph. A few years later the company launched the Super-Sport version. This upgraded variant produced 1200 BHP, a figure which seemed to defy the known limits of automotive engineering at the time. Then came the Chiron and the Chiron Super-Sport 300+. The Chiron's W16 produced an incredible 1500 BHP (Bugatti, 2020) while the aptly named Chiron Super-Sport 300+ had 1600 BHP. It also broke the 300-mph mark by reached speeds of 304 mph (Bugatti, 2020). What Volkswagen has done here is no simple feat. They were the surgeons of a splendorous transplant of what was once the beating heart of aircraft into the powerhouse of fast and luxurious cars. It is a result of design, refinement and testing done over many years. The fact that the Nardo W12 managed to keep running for 4900 miles, at an average speed of 200mph without any issues, is a testament to the W-engines' reliability and sheer power. W-engines powered cars into breaking the 300mph mark and is also the engine of the fastest production cars in existence. You could argue that it was all because of the incredible aerodynamics, computer controls and design. However, it remains an irrefutable fact that the Chiron would not have taken us to the 300-mph mark and beyond without the W16 resting under its bonnet. Therefore, it is safe to say that Volkswagen's W-engines are one of the automotive industries' engineering marvels. They have already sketched their place on the murals on the walls of history, with the records earned from within the heart of incredible technological marvels likely to remain unchallenged for the foreseeable. However, there is more space on the walls of history for many more murals filled with more notable achievements in the future.

Edited by Harsh Sinha

Our house is on fire: what can engineers do to mitigate climate change?

Ansh Sharma (Y13)



Global Warming is a result of excess greenhouse gases being released by primarily artificial processes. One major contributor to these emissions is building construction. Since the Industrial Revolution, these human-generated emissions have been increasing at an unprecedented rate, yet their associated problems have only recently begun to be tackled.

Carbon emissions associated with buildings are currently responsible for 39% [1] of global energy emissions; this essay will discuss two potential solutions to reduce the construction industry's impact on climate change: first, applying carbon capture to concrete and cement will be considered. Second, the novel concept of self-healing concrete will be explored.

Carbon capture technology is being explored extensively in non-building related contexts already such as extractor farms and has shown some promising results. Recently, this technology has been shown to be implementable with concrete and cement as well. Generally, Carbon Capture and Storage (CCS) technology removes carbon dioxide from the atmosphere, converts it into a form that can be transported, and then stores it in either depleted reservoirs or other deep formations – this process is known as Geological Sequestration. The extracted CO_2 is typically stored in a supercritical condition which requires the environment to be maintained above 31.1°C and 72.9 atm.

Normally, the form of CCS is categorised by its position in the process relative to combustion, either post-combustion or pre-combustion. However, in the construction context, the capturing takes place during the making of concrete/cement. The major benefit of this kind of technology is that carbon is removed directly from the air and can allow processes that are usually very polluting to be considered as carbon neutral. For example, any CO_2 evolved from the decomposition of limestone in the cement making process is contained and prevented from being released. When limestone is heated to high temperatures (~1500 °C), CO_2 is released along with quicklime (CaO). The resulting clinker (resulting residue from the kiln) is then cooled and mixed with other raw materials such as limestone to make cement. However, it is possible to reduce the carbon emissions by up to 70% by first heating the mixture to a lower 1200 °C and then cooling the mixture by injecting CO_2 gas instead of using water [2] for the curing process. This not only saves costs (by approximately 30% [3]) and water, but also absorbs the CO_2 gas into the cement as it cools, preventing any gas escaping into the atmosphere. Using this technology, the CO_2 evolved from the heating process can be contained and thus reduces emissions of this potent greenhouse gas.

Furthermore, the resulting concrete that has absorbed this CO2 has a similar strength to regular concrete (which uses non-carbon-capturing cement, such as Portland Cement). For example, CarbonCure, a CCS company, captures CO_2 by dissolving it in water and then reacting it with calcium cations to form calcium carbonate (limestone). They then embed it within their cement – the resulting concrete can withstand 4100 psi whereas a regular control withstands a comparable 4080 psi [4] . Thus, the strength of concrete is not compromised. In fact, less carbon-captured cement is required to reach the same strength in compression in concrete as a regular cement mix. As cement is an expensive component of concrete, this results in a lower cost for the same strength. Therefore, there is an incentive for the construction industry to utilize carbon capture technology from a financial standpoint. Unfortunately, there are drawbacks to this technology – this process can only be done under a controlled environment, and will require a few years before it is available for adoption across the industry.

An alternative strategy is to utilise the qualities of self-healing concrete. Currently, the lifespans (expected operational time) of buildings are only two to three decades. This means that even if the concrete and

Figure 1—Autogenous Healing

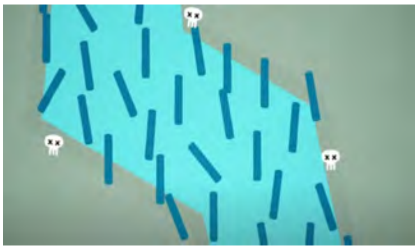


Figure 2—Crystals of $CaCO_3$ filling

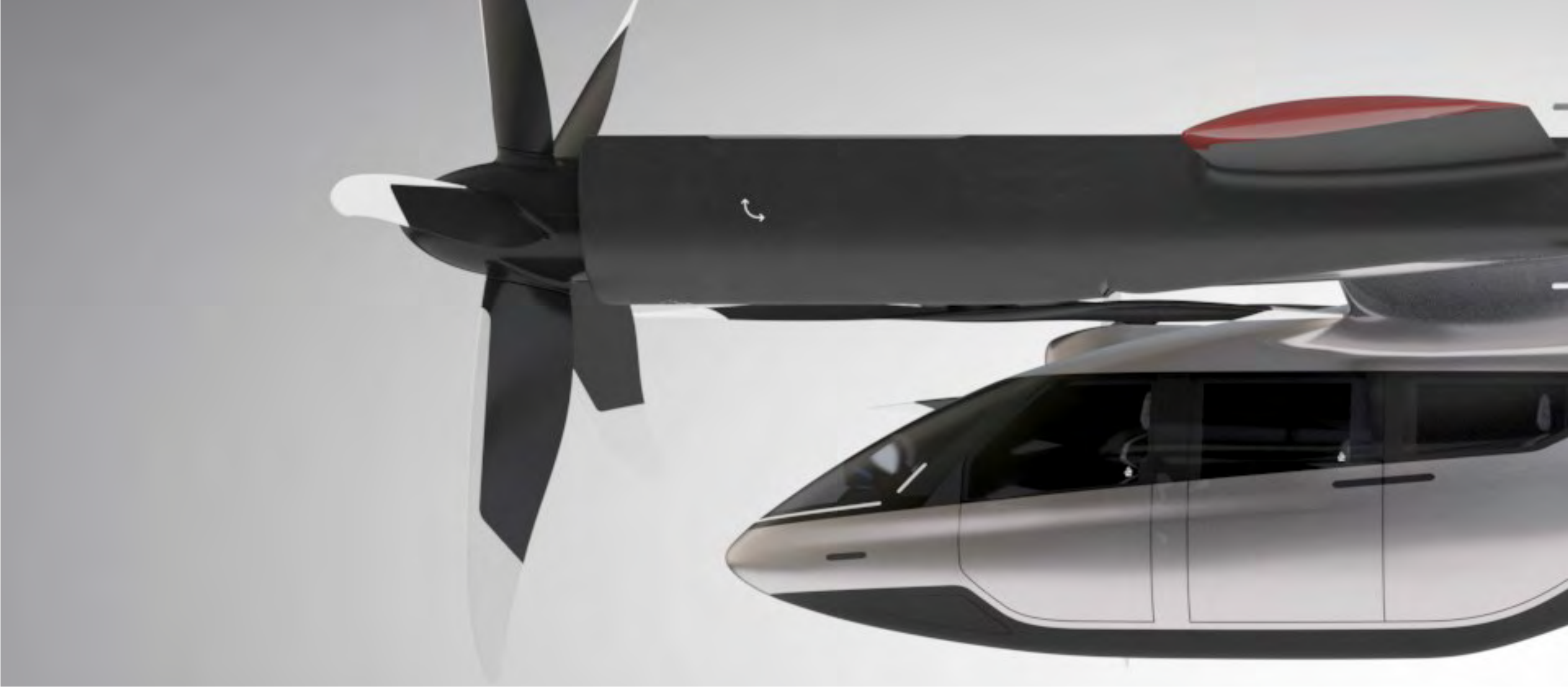
cement mixtures used become greener and closer to carbon-neutral, buildings still must be demolished or repaired to ensure that safety regulations are met and maintained. In order to reduce the emissions due to the demolition and reconstruction of buildings, it is vital that the number of demolition cycles are also decreased. This is achievable by increasing the lifespan of buildings, so they don't deteriorate as quickly. Self-healing concrete appears to provide a solution to this problem. Normally, cracks in concrete can form as a result of concrete shrinkage, temperature variations (particularly the freezing and thawing of concrete), and the significant loads often supported by concrete structures[5]. The maintenance cost required to repair these cracks and keep buildings operational is often remarkably high. Cracks can also expose secondary supports such as steel beams, which may lead to corrosion and rusting, endangering the lives of the people using the building. However, self-healing concrete can fill these gaps automatically.

A process known as Autogenous Healing allows the concrete to repair itself when it undergoes hydration. The Calcium Oxide (CaO) already present reacts with the incoming water to become Calcium Hydroxide ($Ca(OH)_2$), which reacts with the Carbon Dioxide (CO_2) in the air to form Calcium Carbonate ($CaCO_3$). The resulting crystals will then fill the cracks and 'heal' the concrete. Despite this convenient solution, the lifespan of a building is not extended substantially due to the restricted interior access for CO_2 and the limited range of cracks that this can fix – any crack with a diameter above 0.3 mm will not be repaired by this mechanism [5].

Fortunately, another solution can be found using bacteria and fungi to help in the healing process. Bacteria can form calcium carbonate when they change their environments to encourage bacteria formation – this process is known as Biomineralisation [6]. It has been reported that cracks with a depth of 27.2mm have been healed and compression strength has been improved by up to 40% when compared to a control [7]. Bacteria alone can do this in 3 different ways [8]. The first and most efficient method is when ureolytic bacteria catalyse the hydrolysis of urea into ammonium in order to raise the pH. However, this can lead to the emission of Nitrogen Oxide, another greenhouse gas. Furthermore, the ammonium may cause further damage as it converts to nitric acid over time and thus undermines the entire purpose of extending the building's lifespan. Hence, while this is more efficient and successful, the rate at which this occurs must be handled delicately to ensure the result is beneficial. The second method involves calcium carbonate being produced as a result of an organic compound, such as an acid, being aerobically oxidized to produce carbonates. These carbonates will then react with the already present calcium to form calcium carbonate precipitates, which fill the cracks. The drawback to this method is that as oxygen is a limiting reagent, it can greatly slow down the process when in limited supply. For example, foundations of a building which are underground may not benefit from this method. The final method using bacteria again requires organic compounds to be oxidized but this time, aerobic conditions are not a requirement. This occurs in a process known as nitrate ammonification (or dissimilatory nitrate reduction) whereby the microbes respire, resulting in the precipitation of minerals. However, the major disadvantage to this method is the inefficiency present compared to the other two methods.

Alternatively, fungi [9] have the capacity to undergo both biomineralization and organomineralisation (where an organic compound can encourage the mineral crystal being formed to grow further [10]). Due to the chitin present in their cell walls, the activation energy for nucleus formation is lowered, which in turn allows the interfacial energy between the fungi and the surrounding minerals to also reduce. This results in calcium cations binding onto the cell walls. These can then interact with the soluble carbonate anions and thus form calcium carbonate and fill the crack. The disadvantage for this method, and to an extent in the biomineralization methods for bacteria, is that they have been explored extensively in controlled environments and independently as spores but must be integrated with larger structures and at larger scales successfully before implementation in industry as a sustainable technology.

For all of these solutions to be deployable, it is vital that they are made more flexible and accessible so that any company can use them outside of the lab. Between them, I believe that carbon capture technology will be more worthwhile as the initial step because it can immediately render the production of concrete close to carbon neutral. While extending the lifespan of a building is important, I believe that self-healing concrete can be explored as a subsequent step to reduce carbon emissions even further. It should not be the primary plan as it does not directly combat the problem of climate change to the extent of the former option here. Hence carbon-capture technology and self-healing concrete are potential options to mitigate the effects of buildings towards climate change. **Edited by Harsh Sinha**



Saving Money and the Planet: Electric Aircraft

Aditya Vishwanathan (Y13)

Burning the Earth and Burning Money

2.4% of all CO_2 emissions in 2018 came from commercial aviation[1]. The idea that the airline industry is bad for the environment is well known, but it is a problem without many clear solutions – modern aircraft use less fuel and therefore pollute significantly less than older aircraft, but this is reducing the problem, not solving it. Furthermore, the cost of fuel is a significant part of an airline's expenditure, accounting for between 19.1% and 32.3% of airlines' worldwide expenditures in the previous decade[2].

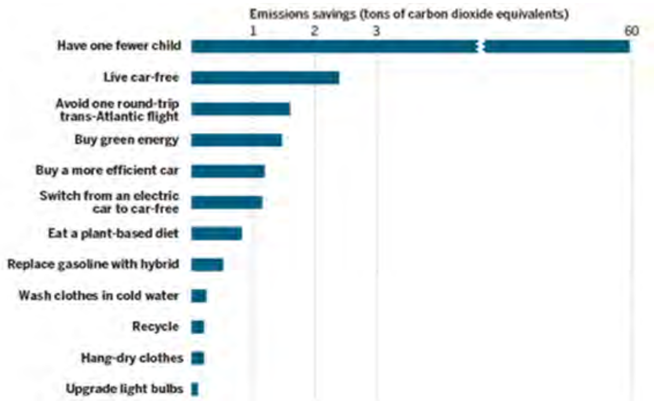


Figure 1: A visual representation of the impact of flying

A Brief Introduction to Aircraft Engines

A typical turbofan (the kind of engine seen on most modern airliners) works by compressing air travelling through the engine core, mixing it with fuel, igniting it and passing it through a turbine and out of a nozzle at the back. As the ignited air passes through the turbine, energy is transferred to the turbine which in turn causes the compressor and fan to rotate, thereby keeping the cycle going. This process produced a small proportion of the total thrust. Most of the thrust is produced by accelerating air that flows around the engine core, thereby producing a force using Newton's Second Law. Using Newton's Third Law the "equal and opposite force" propels the aircraft forwards.

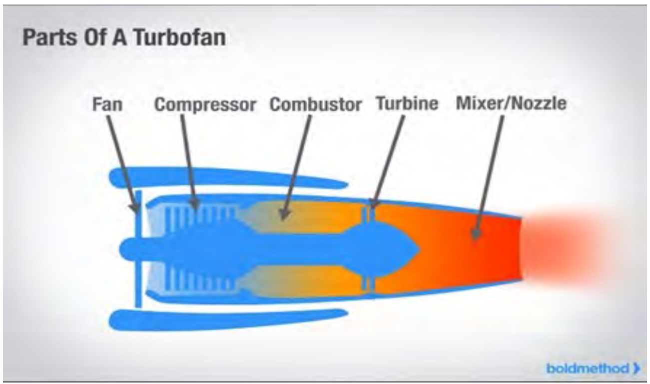


Figure 2: A turbofan engine

An electric aircraft would remove the need for fuel to be ignited and passed through a turbine to keep the cycle repeating – instead, an electric motor would rotate the fan which would accelerate air as before. This would remove the need for jet fuel (and therefore, remove the emission of greenhouse gases from the engine) and likely reduce noise as well.

What's the catch?

Batteries are not an energy-dense medium of storing energy. The best lithium ion batteries have around 265 Watt hours per kg, or 0.95 Mega Joule (0.95MJ) per kg of mass[3]. In comparison, kerosene (commonly referred to as jet fuel) has around 43MJ per kg, so it is clear that to provide the same amount of energy as traditionally powered aircraft, battery powered aircraft would need to be heavier, which means more batteries are required and the problem gets worse[4]. For example, a Boeing 737-300, a fairly old airliner seating around 150 passengers requires 7.2×10^6 watts to fly at a constant altitude and speed[5]. Over the duration of a typical 2 hour flight, the plane would require 7.2×10^6 watts x 7200 seconds, equal to 51,840MJ, or 51,840 kg of battery. Combined with the aircraft's mass, the mass of passengers and any cargo, the issues with battery weight can be seen.

Figure 3: The all-electric Cessna Grand Caravan

Is it possible for aircraft to be electric?

So far, the largest fully electric aircraft to fly is a modified Cessna Grand Caravan, capable of flying 4 to 5 passengers a distance of 100 miles[5] (compared to a capacity of 10-14 over 1050 miles for the conventionally powered type[6]).

Although this does not sound encouraging, the energy cost for the 30 minute test flight was $6, compared to $300-400 using traditional fuel[7]. However, the added weight of the aircraft poses several significant issues when scaled up, as shown in the example above. Due to the constraints of current technology, it is unlikely that airliners will turn electric in the near future, though the signs for smaller aircraft look promising. A key contender for humanity's path to sustainable aviation is hybrid aircraft. These aircraft work in a similar manner to conventional hybrid cars, where an electric motor and engine work in tandem to power the vehicle. Unfortunately, most of the concepts currently being developed are relatively small[8]. Perhaps more worryingly, the main concept showcasing this technology on a large scale, the 100 seat "E-Fan X" developed by Airbus and Rolls Royce, has been cancelled[9].

In conclusion, the wide scale electrification of large aircraft is not something we will see in the immediate future. However, the technology exists and is constantly improving, driven by huge demand for more energy dense batteries in the automotive sector. Although it may not be soon, there is hope that we may have electric birds of metal gliding overhead in the future

Edited by Harsh Sinha

Your ECU - What Can It Do For You?

By Kishok Sivakumaran (Y13)

When it comes to any internal combustion engine, whether it be a straight 6 or V8, petrol or diesel, they all propel the car forward thanks to a seemingly simple sequence:

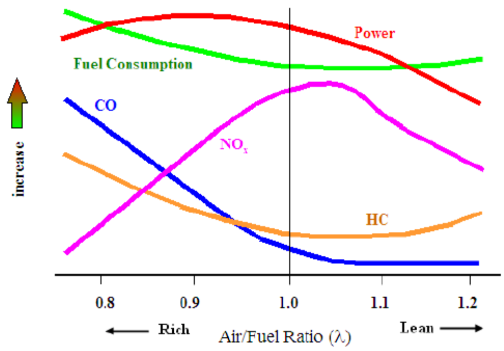
Suck- Intake valve opens to allow an air-fuel mixture into engine.

Squeeze- The piston compresses the mixture in the cylinder.

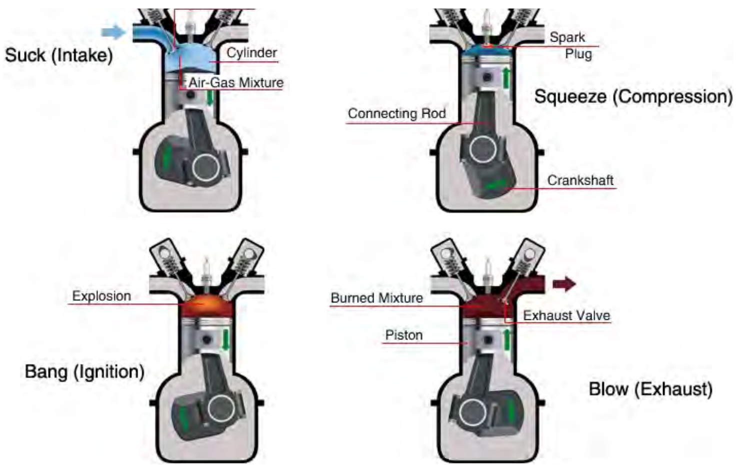
Bang- The spark plug ignites the compressed mixture resulting in power being produced, pushing the piston back down.

Blow- The piston rises back up and the exhaust valve opens to push the exhaust gases out of the cylinder before the sequence repeats.

However, this process must be precisely controlled as even a slight change in the mixture could result in catastrophic engine damage Thankfully, engineers use an ECU to fine-tune all the small details involved in efficient combustion of fuel.



Graph illustrating the many trade-offs ECU programmers must perfectly juggle to suit their target market needs as well as government regulations



Illustrated portrayal of the intake, compression, ignition and exhaust process

What is an ECU?

An Engine Control Unit (ECU) is an embedded computer system used in the automotive industry to control a series of components such as: intake and exhaust valves in an engine, fuel injectors, etc. These can all be tweaked to attain optimal engine performance. It is able to do this by reacting to a myriad of sensors throughout the engine measuring everything from air temperature to concentration of O2 in the air fuel mixture.

What exactly does the ECU control?

Air-Fuel Ratio- Petrol has an ideal stoichiometric air to fuel ratio of 14.7:1 (this measured by mass). This means that the 14.7 grams of air are required to burn 1 gram of petrol. However, if the ratio is increased to around 16:1 (also known as running "rich"), maximum power can be reached per combustion stroke (refer to Figure 1). Running rich results in excess unburnt hydrocarbons being released into the air (which is responsible for smog) as well as carbon monoxide which could have fatal effects if it leaks into the cabin. On the other end of the spectrum, thermal efficiency and therefore optimum fuel economy can be achieved with a ratio of 12.5:1 (otherwise known as running "lean"). A risk of running lean is the release of oxides of nitrogen (NO$_x$) which contribute to smog and could lead to reduced quality of life where emissions are significant. In addition, car manufacturers must adhere to strict guidelines (with the EU emissions targets for consumer vehicles being 95g/km). This and consumer preferences unfortunately mean that manufacturers such as Mercedes, Nissan and BMW are being forced to compromise between performance and fuel efficiency. Generally, cars are programmed to be more on the eco-friendly side in light of climate change concerns.

Ignition Timing- Ignition timing is a vital component of an engine's performance; it determines when exactly the 'bang' happens in a piston. The timing of the ignition is paramount as if a spark is generated too early, (as shown by the red line in figure 6), the piston is forced down while moving upwards. If the spark is generated too late then, energy used to compress the gas is wasted. In both cases, engine knock is developed (where the air-fuel mixture is combusting in two different places). Named after the pinging sound it creates, knock is responsible for the gradual degradation of pistons due to the intense pressure and heat which can lead to cars being less reliable. ECUs play an important part in knock prevention. In order to reach optimum performance and fuel efficiency, the peak pressure caused by combustion in the piston must when the piston is at its highest point and the air-fuel mixture is compressed the most. When the spark is triggered, it takes time for the peak pressure to be generated. As a result, the spark must be generated before this so that maximum fuel efficiency and performance can be achieved. Much to engineers' dismay, at higher RPMs (revolutions per minute) knock begins to occur and increases NO_x emissions due to increased temperature and pressure in the piston; this is where the ECU will use knock sensors and sensors to measure the angular position of the crankshaft to retard (delay) the ignition as RPM increases. Retardation reduces piston temperature to reduce NO_x emissions and knocking at the expense of power and fuel consumption. Yet another compromise that must be made with utmost precision by engineers as well as auto tuners.

RPM Limits- Most cars have a rev limiter to stop the RPM value from going too high or ‘redlining’. This is put in place by manufacturers to minimise engine wear to increase reliability and lifespan on their product. This is controlled by the ECU which uses the crankshaft position sensor or the camshaft speed sensor. If RPM levels reach a value which engineers deemed harmful to the engine, the ECU will either take action to prevent this by either shutting off the fuel injectors or by shutting off the spark plugs completely (hard-cut limiter) or partially (soft-cut limiter). Environmental and concerns around fuel efficiency means that it is more common that the rev limit is enforced by stopping fuel injection as spark shut-off method results in fuel still being injected into the piston, which could burn in other parts of the car and cause unburnt hydrocarbons to circulate through the car which could burn in the exhaust, damaging the catalytic converter with high temperatures as well as wasting fuel.

Speed- The most obvious function of the ECU is its involvement in speed control. As the driver presses their foot on the accelerator further, the air going into the engine increases, the O_2 sensors communicate with the ECU and the ECU induces a response through increasing the release of fuel through the injectors to increase the speed of the vehicle. Speed is reduced by lifting foot off pedal and the fuel injectors are instructed by the computer to reduce volume of fuel input into the engine.

Tachometer on a BMW, with redline between 5500 RPM and 6000 RPM

Launch control- A system on which winning or losing drag races can sometimes hinge on, launch control must ensure that the engine doesn’t fail when revving it to higher end RPM ranges as well as minimise wheel spin to protect the tires as well as reducing wasted energy. This should facilitate maximum possible acceleration to give the drag racer a head start. The ECU is responsible for enforcing the rev limiter set by engineers who have calculated the optimum RPM for maximum torque and acceleration.

The famous Nissan GT-R, known for its explosive launches thanks to the ECU

Safety- The ECU is not just about performance; it also controls the car to reduce the risk of an accident. ABS (Anti-lock braking system) is a safety feature on almost every car today which is used to prevent what is known as locking while braking. This is when the driver constantly has their foot on the brake and the wheels stop completely and end up sliding across the road and thus increasing braking distance (the danger increases when the road is wet). The ECU uses readings from speed sensors in each wheel of the car and compares each value to determine whether the which wheel is going to lock. Once this is known, the ECU sends signals to the brakes to release the brakes to prevent locking and reapplies the brakes when all the wheels are at similar speeds.

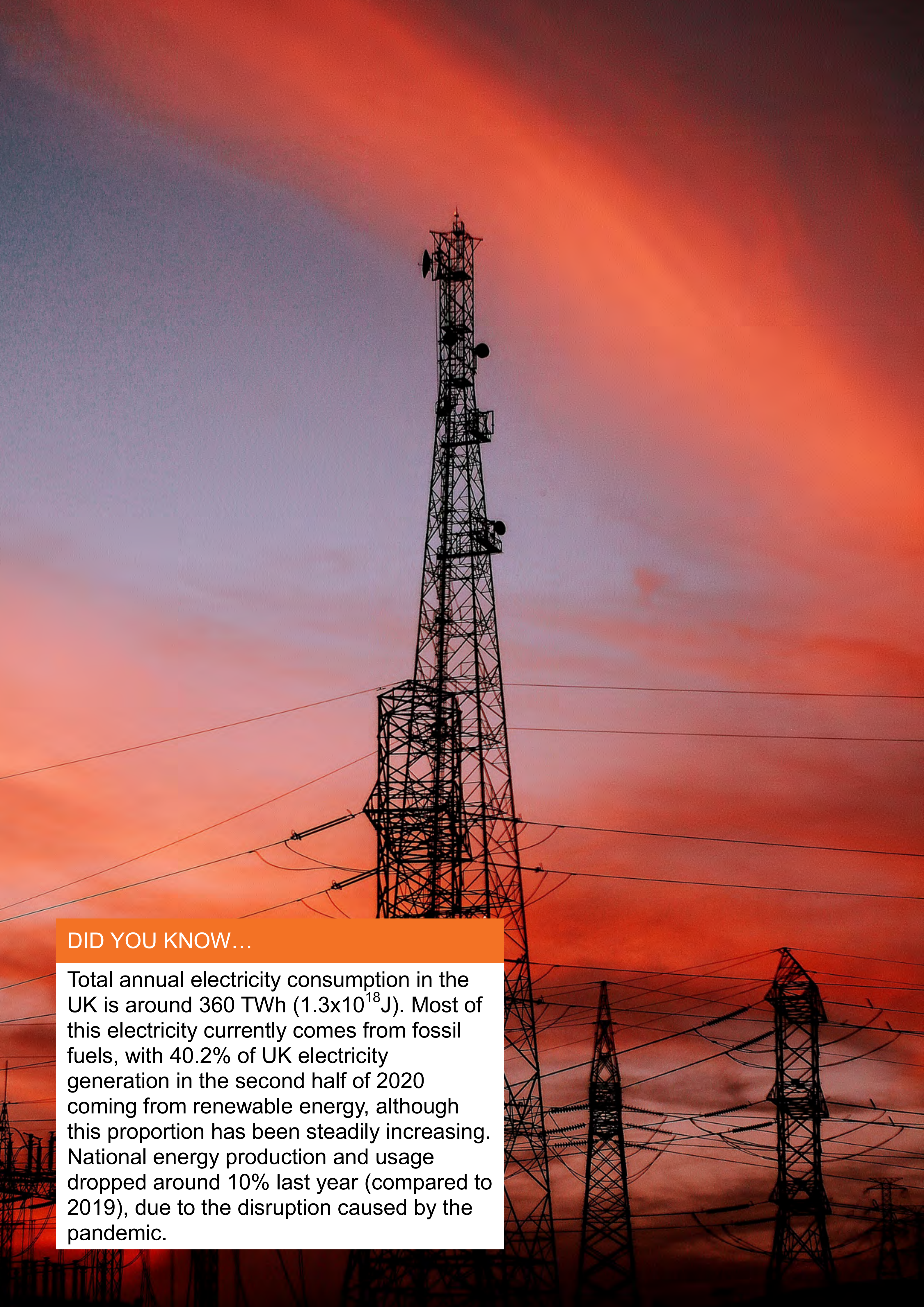
In more modern cars, emergency braking features are implemented by using a variety of sensors: camera, proximity sensors, etc to inform the ECU of its surroundings and if the ECU’s software detects an obstacle that can be avoided by braking, it sends instructions to brake (using ABS as necessary)

Actual ECU from Toyota (made by Bosch) for reference

Environment- The ECU is also responsible for the feature that is being added to many new cars where the engine will stop when it is in traffic. This is controlled by the ECU where if it detects that the engine has been stationary for a sufficient amount of time, it will stop the engine by shutting it off and preventing fuel from being injected. Overall, this saves fuel and reduces emissions drastically in urban areas

From all this information, I’m sure you can deduce that the ECU is paramount to optimum car function; judging from how it is being used to seamlessly integrate more systems used to make cars safer, more economical and squeeze every ounce of performance from them. Despite being a small metal box (see figure 8) lost in a jungle of components under the bonnet, it is not going anywhere anytime soon!

Edited by David Kuc



DID YOU KNOW…

Total annual electricity consumption in the UK is around 360 TWh (1.3×10^{18}J). Most of this electricity currently comes from fossil fuels, with 40.2% of UK electricity generation in the second half of 2020 coming from renewable energy, although this proportion has been steadily increasing. National energy production and usage dropped around 10% last year (compared to 2019), due to the disruption caused by the pandemic.

Artist's Impression of Dark Matter

Why does it (Dark) Matter?

There must be some form of matter which permeates the universe, and yet is completely invisible to us.

By Neos Tang (Y13)

Matter makes up everything we see around us. Our chairs, tables, and even this magazine which you are reading (or the device from which you are reading it) are all composed of matter. It seems, however, that our universe actually contains matter unlike the matter which we know – matter which we cannot see. Surprisingly, it turns out that this "dark" matter is even more prevalent than regular matter, outnumbering it by many times. Some estimations say that dark matter makes up 27% of the universe, outnumbering visible matter 6 to 1 - only a little of our universe is really made of the matter with which we are familiar.

How do we know that dark matter exists?

Through observation, we have learned that all galaxies rotate at extremely high speeds. Our galaxy (the Milky Way), for example, spins at around 210 km/s near the Sun, while much more massive galaxies are projected to revolve at speeds of up to three times that (approximately 600 km/s).

If we were to assume that galaxies are made up of only the matter which we see, then the gravitational forces provided as a result of these masses would not be strong enough to hold the galaxy together – we should be ripped apart. Therefore, there must be some form of matter which permeates the universe, and yet is completely invisible to us, providing sufficient gravitational force to hold our galaxies together. Owing to its imperceptible nature, this matter has been dubbed "dark" matter.

So, what exactly is dark matter?

As we cannot see dark matter, we can say for certain that it does not interact with light (and all electromagnetic waves), or, at the very least, interacts with light very weakly. Since it is very difficult to directly observe dark matter, and as there are many particles and bodies which could meet these criteria, there are many dark matter candidates. Below is by no means an exhaustive list of dark matter candidates, but instead a list of a few, interesting candidates (some of which have been mostly disproved for intriguing reasons).

Neutrinos:

Neutrinos are a type of particle which have no charge, and very little mass. Due to their lack of charge, their electromagnetic interactions are very weak, which fills the criteria of being "dark" - very hard to detect. If there were enough neutrinos about, these tiny masses could combine to form enough mass that significant gravitational forces are observed.

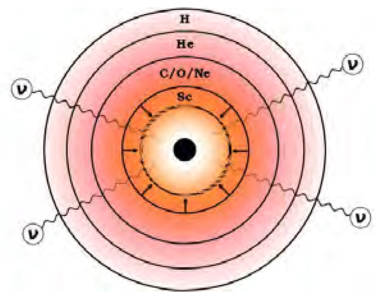


Figure 1: Neutrinos released from a Super Nova Explosion

Such quantities of neutrinos would have been formed at the beginning of the universe – the Big Bang. Tons and tons of neutrinos would fly off from the explosion, carrying enough mass to hold galaxies together. For these reasons, the neutrino might initially seem to be a rather good candidate. Unfortunately, the neutrino has been essentially disproved as a candidate – due to the extremely high energies observed in the Big Bang, neutrinos would be travelling very quickly, described as "hot". This type of "hot" dark matter would lead to the formation of dense galaxy clusters with large gaps in between, rather than the creation of the galaxies we see today.

MACHOs:

Massive Compact Halo Objects are not individual particles, and instead are bodies composed of regular baryonic matter (such as protons and neutrons). Some examples might include a neutron star, or brown and white dwarf stars. These objects emit very little light, to the point that they are difficult to observe. One of the only ways in which MACHOs could be detected is by looking for "gravitational lensing", when light rays from a star are bent by the significant gravitational forces from the MACHO, resulting in an ever-so-slight brightening of said distant star.

Through this method of observation, it has been found that there is likely not enough matter contributed by MACHOs to make up all dark matter, but they do likely make up ~20% of dark matter (with the rest still a mystery).

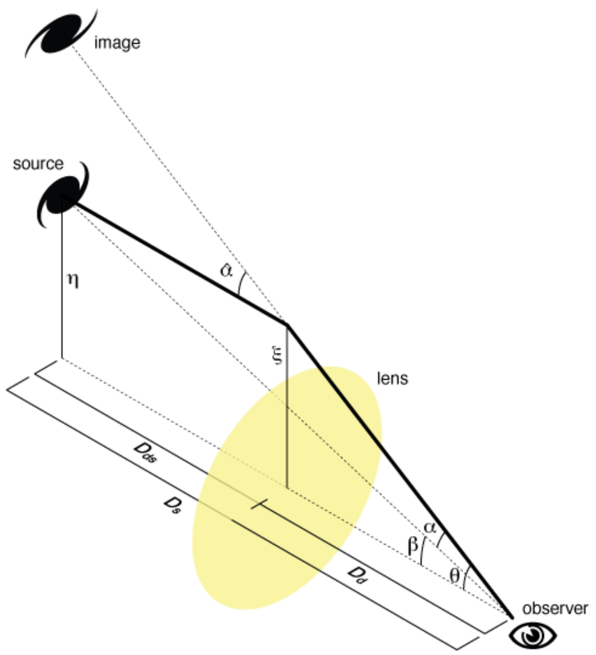


Figure 2: Gravitational Lensing Angles

WIMPs:

Weakly Interacting Massive Particles are yet another candidate for dark matter. Most of these particles are part of "supersymmetry", a theoretical symmetry of nature which provides each particle in the Standard Model with a "superpartner" - the superpartner of bosons are fermions, and vice versa. The most important property of superpartners for dark matter is their very high mass, alongside (for some of these superpartners) their lack of electrical charge, interacting very weakly with the electromagnetic force – a dark particle.

Out of all supersymmetric particles, the lightest supersymmetric particle (LSP) is likely to be the dark matter particle. Sadly, supersymmetric particles are yet to be observed, but are being thoroughly searched for.

Axions:

Originally a particle theorised to solve another issue within particle physics (charge-parity symmetry violation), axions would be chargeless, and very light – perfect for being "dark". Unlike neutrinos, axions would form "cold" dark matter rather than hot, increasing the viability of their dark matter candidacy. Some have referred to axions as "the cousin of the photon", a massless, chargeless particle, except axions just have a little added mass. Just like WIMPs, axions are yet to be seen, but experiments are underway to find them, if they do indeed exist.

Realistically, there is no real way for us to define all dark matter - not until we find it. We do know that MACHOs make up a small portion of dark matter, but sadly the rest remains a puzzle. Perhaps this is why the search for dark matter remains so exciting – with new theories popping up everywhere, usually neither provable nor deniable, this physics beyond the Standard Model feels almost like Sci-Fi. For now, the best we can do is to keep up with ongoing theories and experiments. With the University of Washington looking for axions, and with CERN starting up the LHC again in 2021, expanding their search for supersymmetric particles, we are closer to finding dark matter than we ever have been before.

Edited by Utkarsh Sinha

The Miyun Synthesis Radio Telescope, Beijing

Radio Telescopes

How To Build Your Own Radio Telescope

Leo Kavanagh (Y11)

Radio astronomy is very similar to “normal” astronomy, with the only difference being that, instead of using an optical telescope to study visible light coming from space, a radio telescope is used to analyse radio waves which have been emitted.

Radio waves have a far higher wavelength than that of visible light, with lengths ranging from 1 millimetre to over a kilometre, as opposed to the much shorter wavelengths (380-740) nanometers of visible light. Analysing radio waves has several advantages, such as that they are large enough not to be obscured by particles in the Earth's atmosphere, enabling radio astronomy to be performed at all times of day, in all weather conditions, while also passing through stellar dust clouds that would normally block objects from view. Moreover, the larger wavelength of radio waves means that they are less sensitive to defects in the antenna (which plays a similar role to the lens in an optical telescope), and so radio telescopes are much less demanding to make at home with limited tools and experience.

A very popular target for radio astronomers is something known as the hydrogen line - the signal emitted by hydrogen gas in space. All hydrogen emits radio waves at a wavelength of roughly 21cm (or a frequency of 1.42GHz), and, seeing as most stellar objects contain large quantities of hydrogen, this is a good frequency to monitor to detect them. In particular, my goal was to detect the spiral arms of our own galaxy, the Milky Way. Since our galaxy is full of stars and clouds of hydrogen gas, the intensity of radio waves at 21cm being detected should increase whenever an arm passes overhead. Armed with this knowledge, I set out to build my own radio telescope in order to observe this phenomenon.

Radio telescopes consist of 3 main parts: the first is the antenna, which focuses incoming radio waves (the most recognisable type of antenna is a dish). Next is the feedhorn, which focuses these waves even further and “funnels” them into one point, normally in the shape of a box or a can. Finally, we have the probe, which is normally within the feedhorn, and serves to actually pick up the radio signal and turn it into an electrical signal - usually just a piece of copper wire. The signal is carried from the probe through a series of coaxial cables (often used for transmitting television signals through a device known as a Low

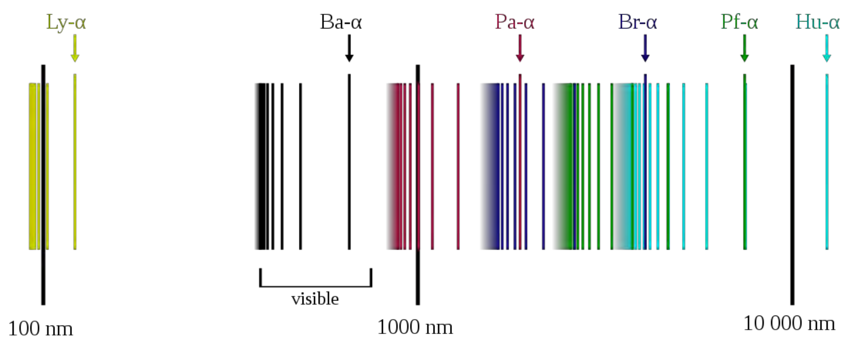


Figure 1 - The hydrogen spectral series

Noise Amplifier (LNA)), which amplifies the signals at the frequencies of interest while cutting out as much noise as possible.

I was initially drawn to buying a satellite dish to use as my antenna, but soon realised that the less well known horn antenna design was both more space efficient and much more interesting to work with, as I would have to construct it myself. This design simply involves an upside-down pyramid shaped horn made out of a material that reflects radio waves being placed on top of the feedhorn. After consulting an online tutorial[1] I found that my feedhorn should be roughly 20cm in height, and a quick visit to Wikipedia[2] gave me a formula for the best possible dimensions for my horn given the frequency I was observing. To construct the horn, I bought three panels of aluminised foam board which I cut to make the panels of the horn, which I coated with aluminium tape for maximum reflectivity. For the feedhorn, I bought a biscuit tin and sawed off the top, before drilling a hole in the side for the probe, which the tutorial[1] said should be about 5.3cm long, and about 17cm from the open end of the feedhorn. The probe itself I cut out of a piece of copper wire. I inserted it into an N-type bulkhead connector (one of the coaxial connectors I mentioned earlier), which had an SMA output (another type of coaxial cable), which I attached to a 10cm SMA cable (keeping the cables as short as possible to minimise unwanted noise), which then connected to the LNA that I bought. This outputted into a 3m SMA cable which led to a USB SDR (Software Defined Radio) dongle, which took my radio input through an SMA cable, digitising and transmitting it to my computer via a USB port.

However, before using my telescope to observe anything I first had to calibrate it - that is, measure the signal coming from the surroundings and the electronics in my system (such as my LNA), so that I could then subtract these unwanted signals from my observation data, leaving only the relevant signal coming from the Milky Way. The unwanted noise signal looked like this (the curvy shape is caused by the LNA):

However, even after calibration, I wasn't able to detect anything. This could be for a number of reasons, such as there being poor electrical contact between the N-type plug and the feedhorn (which is necessary for proper signal transmission). Despite this, I encourage you to try this yourself, and I hope that you see some spectacular results!

Edited by Neos Tang

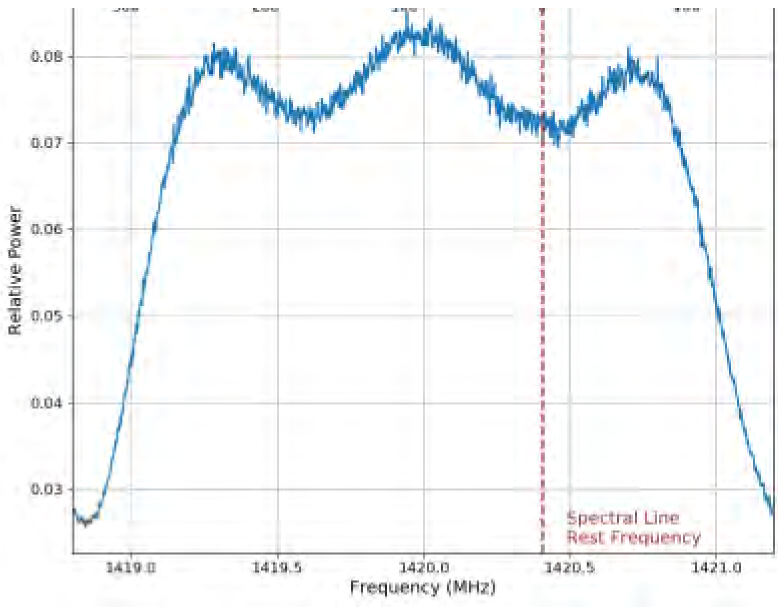


Figure 2 - The signal

Staying in the (Elliptical) Loop

By William Lu (Y12)

What is an ellipse?

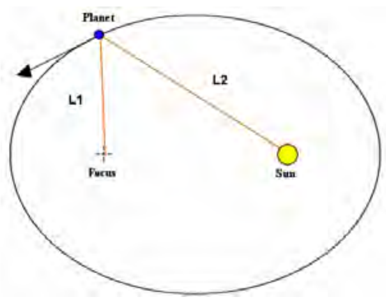


Figure 1– a visualisation of Kepler's First Law

In layman's terms, an ellipse is a squashed circle. Often, an 'ellipse' is confused with an 'ellipsis' (the omission from speech or writing of a word or words that are superfluous or able to be understood from contextual clues).

As if this were not ambiguous enough already, ellipse and ellipsis both have the same plural form: 'ellipses.' Given that this is a physics article, and not a thesis on lexicography, I shall make it clear here that all uses of 'ellipses' are referring to the geometrical shape and not the aforementioned punctuation mark…

If you would like another frustratingly similar astronomical term, I would highly recommend taking a look at the astronomically mesmerising photos of the solar 'eclipse' of Saturn, taken by the Cassini-Huygens Satellite in 2017.

The Law of Ellipses…

The general consensus used to be that the Earth orbits the sun. Throughout scientific history, the layout of the solar system has been a mystery to astronomers. The GCSE course mentions Claudius Ptolemy's geocentric model (that all planets in our solar system and the Sun orbit around the Earth) and Nicolaus Copernicus' heliocentric model (that the sun is at the centre of the Solar system and the earth revolves around the Sun). These two models both don't work, because Ptolemy and Copernicus both assumed that celestial bodies are undergoing perfectly circular motion.

However, a German astronomer in the early seventeenth century; Johannes Kepler was tasked by his mentor Tycho Brahe to observe the orbit of Mars. The data gathered by Brahe was supported by neither of the two concurrent aforementioned models. Consequently, in 1605 Kepler discovered his first law of planetary motion: planets orbit in an elliptical motion, with the sun at one of the foci.

Technically, my description of an ellipsis being a 'squashed circle' was mathematically inaccurate. A circle is a form of ellipsis, but an ellipsis has special properties which disallow it from being classified as a circle.

The shape of an ellipsis' curve depends on an ellipsis having two 'central' points. Each point is called a focus (plural form is foci). If we refer to the current position of the planet along the circumference of its orbit as point P, and call the empty focus F1 and the Sun F2. Next, I shall name the length between P and F1 'L1'. Naturally, I will call the length between P and F2 'L2'. The sum of L1 and L2 should remain constant, regardless of where point P lies on the circumference of the ellipsis

The distance between the foci of an ellipse is known as eccentricity. A circle is technically an ellipse, but a circle has an eccentricity of zero, as the foci overlap each other to form the centre of a circle. Thus, the lower the eccentricity of an ellipsis, the more it resembles a circle. The orbits of most planets are not very eccentric, since the distance between the empty focus and the sun is rather miniscule, in comparison to the distance between the planet and the Sun. Since this is on an astronomical scale, however, this 'miniscule' distance between the Sun and the empty focus still causes massive variations in the distance that planets like the Earth are from the Sun.

The closest the Earth ever is to the Sun (perihelion) is 1.47098074×108 kilometres.5 The furthest distance between the Earth and the Sun (aphelion) is 1.52097701×108 kilometres.6 If you subtract the aphelion from the perihelion, the result is approximately five million kilometres, which is the distance between the Sun and the empty focus.

This may seem like a rather minor discovery, seeing as it happened more 400 years ago. On the contrary, this could not be further from the truth - by understanding the basic principles that determine the arrangement of our solar system; scientists have been able to begin to comprehend and appreciate the beauty and complexity of the observable universe.

"What goes around, comes around…"

Edited by Neos Tang

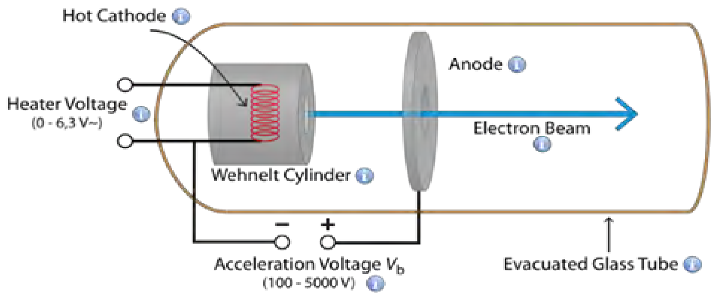
Particle Accelerators and Nuclear Physics

By Dulain Gamage (Y12)

When exploring physics, even broadly, the term "particle accelerator" is inevitably going to crop up- it is in the centre of advancing research in nuclear and particle physics. If the concept was heard about in Newton's time, it would be deemed as fantastical as a time travel is in modern society. Although it may seem that we are entering a plateau of scientific breakthroughs, as we recall revolutionary historical years such as the miracle year of 1905 or Maxwell's theory of electromagnetism, we could not be further from the truth.

Particle accelerators are useful in health and disease, such as understanding immuno-rejection in hip replacement. This is where the body's immune system triggers an autoimmune response (the body's immune system launches an attack in response to the detection of foreign cells). As a result, bones start to reabsorb their own healthy cells due to the metal and plastic on implants releasing polyethylene particles which the body sees as foreign, causing osteolysis. Accelerators can also be used in engineering and manufacturing like casting aluminium. The question is, how exactly do these accelerators lead to such advanced insights. What they do is in its name- they accelerate particles, but they do it to immense speeds- close to the speed of light. They move around in a circular motion, and when they are first being observed, scientist realised there was a certain hazard, - vast amounts of radiation was being released. This led to the discovery of synchrotron radiation in the General Electric Research Laboratory in the 1940s. What was initially deemed a flaw, is now being utilised in many experiments stationed near these accelerators such as spectroscopy. A key thing to note is the accelerated particles must travel in a vacuum in order to remove any obstruction from the direction of travel in the accelerator.

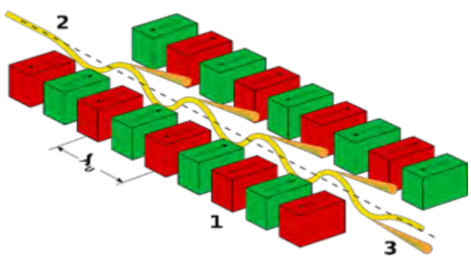
How does the acceleration process begin? We need a source of electrons. The accelerator at



Inside a Particle Accelerator

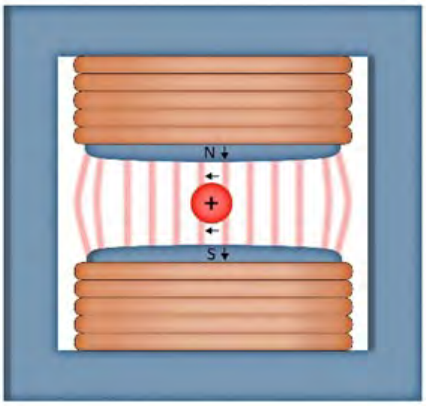
Diamond (a British particle accelerator) uses an electron gun where thermionic emission takes place. In essence, we have a metal filament (which is also a cathode) in which resistive heating takes place when current is passed through, boiling off the electrons (electrons gain enough energy to overcome the electrostatic attraction of the atomic nucleus) from the heated metal filament (usually tungsten). At this point, there is nothing stopping the electrons from moving in any random direction and at slow speeds. To combat this, there is an anode in proximity to the filament, creating a positive potential causing the electron to be accelerated in the form of a beam. This is called a cathode ray. This can be described using the equations $E = QV$, and $E = \frac{1}{2}mv^2$. The electron gains potential energy from the anode- however we also observe that if energy were to increase, either the mass or the velocity must also increase as $E = \frac{1}{2}mv^2$. The mass of the electron remains constant, thereby the velocity of the electron must increase, hence it accelerates. This, however, is not enough to accelerate electrons to high enough speeds. Electric fields are set up at intervals along the accelerator, constantly changing from positive to negative at set frequencies, creating radio waves. This leads to the electron gaining energy in the form of an electrical impulse, and as we have already established, an increase in energy leads to an acceleration. This occurs in a radio frequency cavity.

From this point on, the electron could travel through an undulator. In summary, this is used to produce even more radiation through rapid changes in the electron's path (oscillations). To understand how an undulator works, we need to know what it is made up of. It consists of 2 arrays of permanent magnets with alternating poles (NSNSNS) in parallel with each other with a gap in the middle for the electron to



Alternating Pole Arrangement

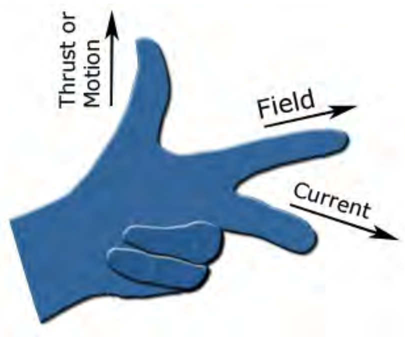
travel. The field of alternating polarity forces the electrons to



Undulator in Action

undergo oscillations hence producing synchrotron radiation. To change the frequency of the synchrotron radiation produced, scientists can change the strength of the magnets in the undulator as the frequency of the radiation produced is proportional to the magnetic field strength.

The electron will travel around in circular motion, accelerating until it reaches the required speed. To bend and focus the electron's trajectory, lattice magnets are used - dipole magnets bend the beam, quadrupole focuses the beams and sextuples correct errors that arise from the focussing of the quadrupoles and octupoles help keep stored particle beams stable. Dipoles work by having two electromagnets of contrasting poles, stacked vertically, facing each other, creating a magnetic field with the field lines traveling downwards. Moving electric charges (in this case an electron but could be a proton as shown in the picture) experience a force when travelling through a

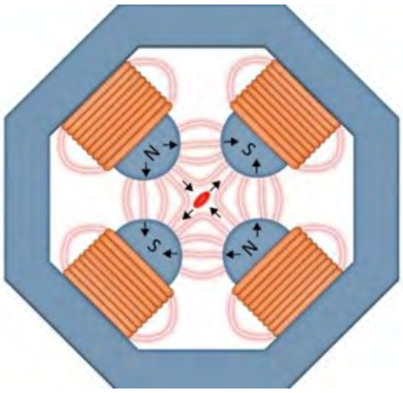


magnetic field. To determine the direction of this force, we must look at something called Fleming's left-hand rule.

This takes the direction the electron is travelling, the direction of the magnetic field, and shows us the direction of the resulting force that is produced by simply orientating our fingers in the correct corresponding directions. In short if the electromagnets are stacked vertically, then depending on the direction of electron travel or which magnet is positive/ negative, the direction of the force will be to the left or right (this can be configured by scientists).

During the process of bending the electron beam, the focussed beam shape may start to deform. A scientist name Jonathon Jarvis, compared these beams to gas molecules where the " random energy causes particles to drift apart " and "slam into the walls of the vacuum pipes" [1]. Quadrupoles have four poles creating a magnetic field that applies an inward force that helps to refocus the drifting electrons. A downside is that this force Is only applied in one plane, meaning the squeezing effect only occurs horizontally, in turn forcing the electrons in an upward or downward direction. However if we have multiple quadrupoles set up in different orientations, then the force will be applied in all directions forcing the electrons into a concentrated point. The strength of the magnets determines the focussing power.

The radiation produced in particle accelerators an be used in spectroscopy which is the study of the interaction between electromagnetic radiation and matter. To understand this, we need to look at how an atom absorbs and emits radiation. Electromagnetic waves carry energy, and so when it reaches an



Quadrupoles have 4 poles creating an inward magnetic force

atom, this energy in the photon is absorbed by the electron, moving the electron to an excited state from a ground state. Each shell of an atom holds electrons with different set energies. And so the electron, when it gains energy moves to a different shell. However when the electron moves back to a ground states, a photon is given off carrying the same energy as the photon that was absorbed. What we can observe here is also the conservation of energy. A key thing to note here is the photon energy required to move an electron from ground state to an excited state is different for different elements. This means that not all types of light can be absorbed and so emitted by any one atom. We can send radiation towards a material, and we can plot the different colours/frequencies of light emitted form the material forming an emission spectrum . We can match this with already documented emission spectra to find the elements present in the material.

To conclude particle accelerators, although invented in the 1930s, are still being continuously developed as scientists work to minimise maintenance cost, decrease acceleration time and increase energy efficiency.

Edited by Divy Dayal

The Confusing 'Active' Nature of Quantum Measurement

By Tathushan Subenthiran (Y12)

The study of quantum physics (the use of maths to make some attempt at explaining details pertaining to light and very small objects) is in many ways a complete overhaul or redefinition of what we are taught at school, down to its very basics. It twists the most seemingly mundane things into wondrous phenomena. One such example of this is how, when respecting quantum mechanics, the act of measurement (determining a detail about a system) is not a passive process but is instead inherently 'active' – when we measure something, the laws of quantum physics show us, unbelievably, that we affect its state.

A true understanding of exactly what is going on necessitates a consideration of what everything is made of – articles in prior issues of the magazine have explored and laid out that a quantum particle is simultaneously particle-like and wave-like. As a consequence, all objects and systems in the universe have a 'wavefunction', calculated by the Schrödinger equation.

$$H(t)|\psi(t)\rangle = i\hbar \frac{d}{dt}|\psi(t)\rangle$$

Figure 1 - the Schrödinger Equation

The equation is pretty complicated, and not directly related to the matter of this article, so I'll refrain from needlessly going off on a tangent.

The wavefunction is relevant, however, and determines all observable properties of an object, and how they will change. In quantum physics, an object or system can only be observed in certain 'allowed' states, and its wavefunction encompasses all of these allowed states simultaneously. Until measured, the quantum particle exists in all these states at once: this is a 'superposition', as explored in other articles. The probabilities of these different allowed states are determined by squaring the wavefunction.

So, what has all this got to do with measurement? It has been found that measurement, an active process as previously mentioned, creates the very reality we observe through its ability to determine what state an object/system is in.

This mind-boggling concept can be seen everywhere – let us consider photons (the quantum, particulate form of light) and their polarisations, which can be succinctly thought of as the direction in which they oscillate. A polarising filter is a filter that only allows photons of a particular polarisation through.

We can explore the active nature of measurement with the *'three polarising filter experiment'*.

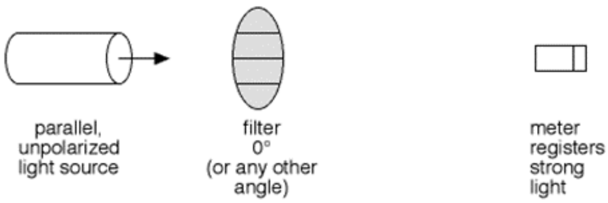
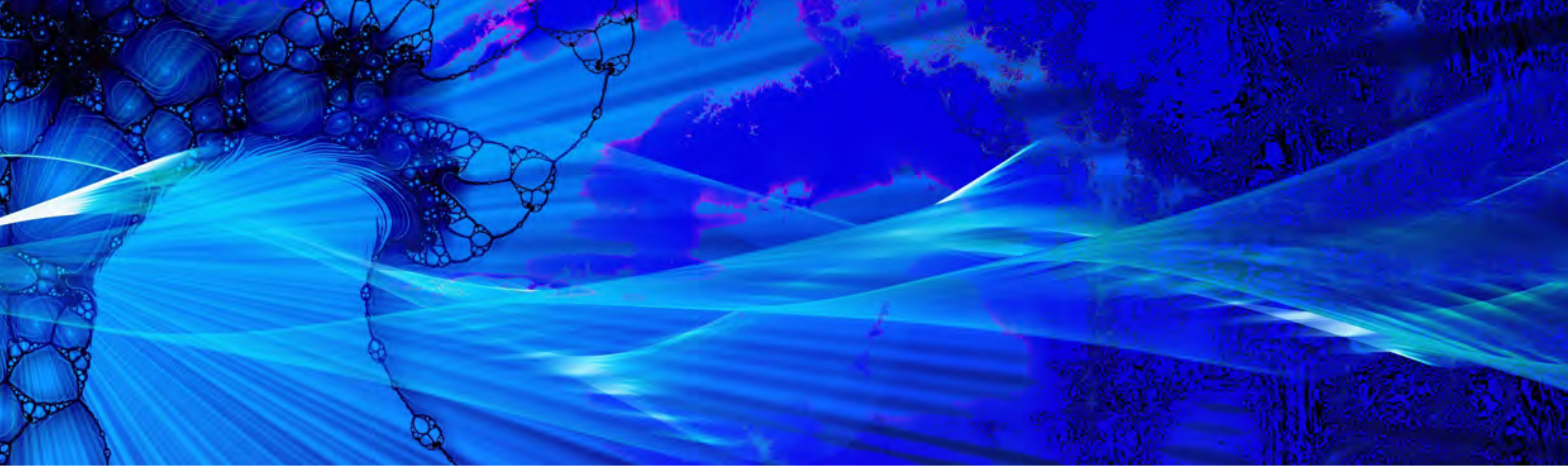


Figure 2 - a one-filter setup

When a stream of photons is sent towards a polarising filter, each photon's polarisation decided at the filter, existing in a superposition until then – this process of measurement occurs as we examine each photon.



The photons that pass through are be polarised to the angle of the filter (horizontal) and make it through to the other side, and the ones that are absorbed must have been polarised at an angle perpendicular to the filter (vertical). This only happened when the photon was measured at the filter, however. Photons are quantised (discrete), and so it is impossible for only part of a photon to pass through a filter – a photon either passes through or is absorbed. Photons have only certain allowed states, and so this polarisation is in superposition until measured, at which point it is measured as either horizontal or vertical – such that the photon is transmitted or absorbed, respectively. An 'in-between polarisation' is forbidden as this would imply that only a part of the photon would get through. If the photon happens to be polarised to an angle between the two, then there will be a probability of absorption and a probability of transmission upon measurement – the photon ends up being polarised to either horizontal or vertical when it meets the filter.

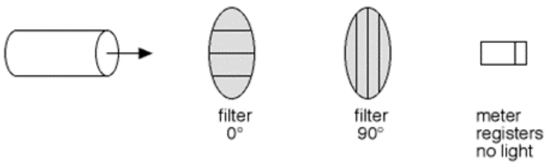


Figure 3 - a two-filter setup

This idea can be tested by introducing a second filter. The now vertically polarised photons are blocked by the second filter, which is perpendicular to the first filter. This occurs due to the nature of allowed states – a photon can be in certain states (vertical or horizontal). Since the photons passed through the first filter (let this be horizontal), their states were measured to be horizontal, and so the vertical filter did not let them through – this is like sneaky red light waves trying to weasel their way through a blue filter: the photons just get absorbed.

For the strangest result, we can add a third, middle filter. The introduction of this middle filter does something funky, and does something that causes some of the horizontally polarised photons to gain a vertical component. It allows them through the last filter, and so the photon detector detects some light (although not as much as with just a single horizontal filter). Where does this stem from? As explored earlier, the different states a photon can be in (vertical or horizontal) have different probabilities of occurring. As the middle filter is 45 degrees from the polarisation of the horizontal photons, each has a 50% chance of making its way through (in accordance to the probabilities of the states based off of each photon's wavefunction). This means that some photons inevitably make their way through the second, 45 degree filter. By the same reasoning, the photons which have passed through the 45-degree filter now have a 50% chance to make it through the final, vertical filter, too , as they are now polarised at an angle 45 degrees to the previous and coming filter. Therefore, we can observe the active nature of measurement: simply measuring the photons' states after the first filter and before the third changes their states such that they can pass through the third filter, rather than being absorbed, as we saw in the second experiment!

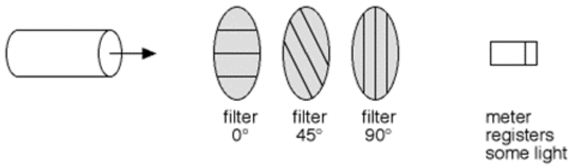


Figure 4 - a three-filter setup

How does this happen? And why? No one really knows – many esteemed physicists have taken a stab at these questions (such as Niels Bohr and Werner Heisenberg with the Copenhagen Interpretation, and Hugh Everett III with the Many Worlds Interpretation), but all of these theories are just that – theories. There has been no empirical proof (or disproof) of any of these countless interpretations, so all we can do is observe and manipulate quantum particles, without the fundamental understanding which we are so used to. It's quite a depressing and resigned approach to physics, but the idea helps a lot with certain calculations. Many physicists do take this 'shut up and calculate' approach, a phrase supposedly popularised by Richard Feynman. I'm a fan of it too , if not just for its humorously blunt title!

Edited by Neos Tang

Eka-caesium

Syed Shah (Y12)

In the 1870s, one of the gaps left in Mendeleev's periodic table was an element that chemists called 'eka-caesium'. After various false discoveries by other scientists, it was Marguerite Perey, then a lab assistant, who in 1939 proved its existence and later named it 'francium' in honour of her homeland.

How did Marguerite Perey discover francium and why – despite what we learnt at GCSE, and what Perey herself thought – is it less reactive than caesium?

Reihen	Gruppo I. — R'O
1	H=1
2	Li=7
3	Na=23
4	K=39
5	(Cu=63)
6	Rb=85
7	(Ag=108)
8	Cs=133
9	(–)
10	—
11	(Au=199)
12	—

Figure 1: Part of a periodic table made by Mendeleev in 1871, with a missing 12th element in 'Gruppe I'.

(The 9th and 10th elements do not exist in this group.)

Discovery

Actinium, element 89, can decay by emission of an α particle (two protons and two neutrons) into francium,

$$^{227}_{89}Ac \rightarrow {}^{223}_{87}Fr + {}^{4}_{2}\alpha$$

element 87, like so:

After extracting very pure samples of actinium and dissolving them, Perey noticed that the radioactivity of the solution was higher than what was expected, suggesting that another radioactive element was also present. As the actinium was (apart from the non-radioactive water) very pure initially, Perey suspected that the actinium must have undergone α-decay into element 87 (which itself must have been more radioactive than the actinium).

To prove this, Perey dissolved caesium perchlorate salt into the actinium solution. Because francium is in the same group of the periodic table as caesium, i.e. group one, the two have similar chemical properties, and so it was expected that, when crystallising the aqueous caesium perchlorate, the francium would precipitate out of solution embedded within the caesium perchlorate crystals.

As caesium-133 is non-radioactive*, Perey could, by showing that these crystals were nevertheless radioactive, prove that another element was present in them. The only possible one this could be was an element produced by the decay of actinium and in the same group as caesium - francium.

Reactivity

In GCSE chemistry, we learnt that the reactivity of group one elements increases as you go further down the group**, so we would – and Perey did - assume that francium would be more reactive than caesium. However, as shown by francium's slightly greater first ionisation energy** (392.26 vs 375.71 kJ mol-1), it is caesium that is the more reactive of the two, but why?

Even though francium has a greater number of shells than caesium, the size of a francium atom is so large that the outermost electron moves at speeds great enough for relativistic effects to become significant...

As an object approaches the speed of light, its relativistic mass increases, as per the following equation:

$$M(u) = \frac{M}{\sqrt{1 - \frac{u^2}{c^2}}}$$

where M(u) is relativistic mass; M is rest mass; u is the object's speed and c is the speed of light.

If we simplify an electron to be a particle orbiting the nucleus, the electron, with its increased mass, will orbit at a smaller distance from the nucleus, and therefore the electrostatic attractive force between the nucleus and the electron will increase, as per Coulomb's Law:

$$F = \frac{q_1 q_2}{4 \pi \varepsilon_0 r^2}$$

where F is force; q1 is the positive electric charge of the nucleus; q2 is the negative electric charge of the electron; r is the distance between the nucleus and the electron and 4πε0 is constant.

The increased force of attraction means that more energy is required for the francium atom to lose its outer electron.

The equation shows that the relativistic mass and rest mass only become significantly different at speeds close to the speed of light, which is why the GCSE trend holds true from lithium through to caesium and only fails at francium.

Edited by Ray Wang

Footnotes

*Caesium-133 (natural abundance 100%) is the only stable isotope of caesium.

**First ionisation energy: "the energy required to remove one mole of the most loosely held electrons from one mole of gaseous atoms to produce 1 mole of gaseous ions each with a charge of 1+." [https://www.chemguide.co.uk/atoms/properties/ies.html]

THE EDITORIAL TEAM: REFLECTIONS ON ISSUES 1-4

In their last issue, the editors talk about how they got into the Wilson's Intrigue, their thoughts about the magazine so far and what drives them to pursue STEM subjects at higher education

Devanandh Murugesan
Chief Editor/ Founder
Medicine

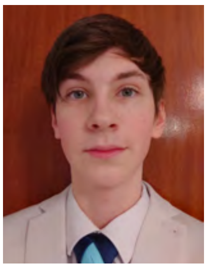
I wanted to create the Wilson's Intrigue to share my passion for scientific research and literacy amongst the school community and inspire others to learn more about their own STEM interests, through scientific journalism. I hope that the Wilson's Intrigue has helped our audience over the past 2 years and now leaves a lasting legacy at Wilson's School, for more students to follow in our footsteps and realise their STEM ambitions.

I am driven to study Medicine because I see the role of a doctor fulfilling more than society's expectations. A doctor exudes an aura of hope and comfort to their patients, helping them through their darkest times by providing holistic, patient-centred care and this is what I look forward to. The academic nature of the profession is linked to my desire to promote scientific understanding—empowerment and autonomy through knowledge. With science, the impossible becomes possible and beneath every discovery we make another mystery lies, like Matryoshka dolls—a piece to a puzzle hidden inside another.

Utkarsh Sinha
Deputy Chief Editor
Engineering

My Intrigue experience began when Dev came to me at the beginning of Year 12, a cross between Bill Gates and Nanny McPhee, with an idea. I now see that what then seemed to be an offhand remark about starting a science magazine was actually the result of at least a few weeks of contemplation. I immediately nodded my acquiescence at the time, and our first meeting in S5 followed shortly afterwards. The rest is history. The Intrigue may be the best thing to come out of my Wilson's Sixth Form experience. It has allowed me to keep writing, something that I have always loved, despite my STEM-only A-Level options. As an editor, everything that has grown and taken shape in the journeys between my hard drive and those of the writers has taught me something I was otherwise completely unaware of. During this year, a community has formed where none existed previously, and I look forward to taking on similar roles at student-run publications wherever I spend the next few years of my life. To those further down the school, I implore you to take up this opportunity whenever it becomes available to you.

I'll be doing Mechanical, Automotive, or Design Engineering if I stay in the UK. If not, then I see a return to behavioural economics or even academic research in my future, but the sky really is the limit. I decided on these courses because I have always been interested in how humans interact with the world around them. Engineering allows me to view this from a technical standpoint and is the first step on the way to designing products that are both truly pleasurable to use and functionally superlative.



David Kuc
Editor
Computer Science

I originally joined the science magazine as I wanted a way to focus myself on learning new aspects of the subject I enjoyed. You can easily say that you want to read up on AI or Software engineering. But when you write about a topic, you often find that there are aspects you are unsure about and have to look up those things, allowing you to understand depths that you might not have even noticed. For example, try explaining the process behind a mathematical function like sin(x) and you might realise how little you actually know. Throughout my time with the science magazine, I have been able to write about topics that interest me, talk to other people with similar interests and edit articles covering a variety of topics, resulting in newfound appreciation for subjects I previously didn't enjoy as much during GCSE.

I plan on doing a masters degree in Computer Science. Science teaches us the causes behind phenomena and allows us to predict the consequences of our actions on a fundamental level. So through the pursuit of science, you can understand how to change aspects of the world around you. The reason I chose computer science is because when writing a program or developing a processor from transistors, you can create whatever you want and freely customise it to your personal tastes, allowing you, in some cases, greater freedom than you might find in reality.

Harsh Sinha
Editor
Engineering

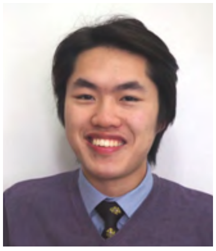
When Dev initially approached me with the idea of starting a Science Magazine, I agreed in an instant. Work over the months that preceded that fortuitous WhatsApp message had led me to hold the belief that engineering in isolation was irrelevant without an understanding and application of other fields. This opportunity seemed too good to miss, a chance to broaden my own knowledge while contributing to the creation of a resource which could do the same for others. Agreeing to join Dev on this journey, I knew that he would put his all into making it as professional as possible. I also knew that he would understood the importance of building a strong core team to start the magazine. What I couldn't have anticipated at the time was the pace at which the magazine flourished, creating a strong community of people who, arguably, have a greater thirst for knowledge than any other society in this school.

I will be studying Engineering at university, perhaps dabbling in Computer Science and Economics in my free time, but I will always be backed by the experience I have gained from my time at the Wilson's Intrigue.

Michael Lowe
Editor
Computer Science

Being an editor and writer for the Wilson's Intrigue has been such a joy. I've not only been able to explore topics that interest me, but I've also been able to see the magazine evolve: from an idea in Dev's head to a publication that is improving with every new issue and a community of students that share my passion for science.

Next year I hope to study Computer Science at university, a subject that particularly fascinates me because of how fast much of the technology is created, exploited and improved. I hope that the magazine continues to thrive after we are gone.



Neos Tang
Editor
Physics

I joined the magazine as it provided an excellent outlet for the presentation of research about any topic (within reason) I fancied. Rather than traipsing aimlessly through the wild jungle of the internet, writing focused articles has been much more helpful in expanding my breadth of knowledge. Being an editor has allowed me to develop many skills, such as critical reading, setting and meeting deadlines, navigating through publishing software. But most importantly, in my opinion, it has matured my interpersonal skills. As an editor, teamwork and morale-boosting are essential. It has been a delight to work alongside such an excellent team of writers and editors, who have made this so much fun.

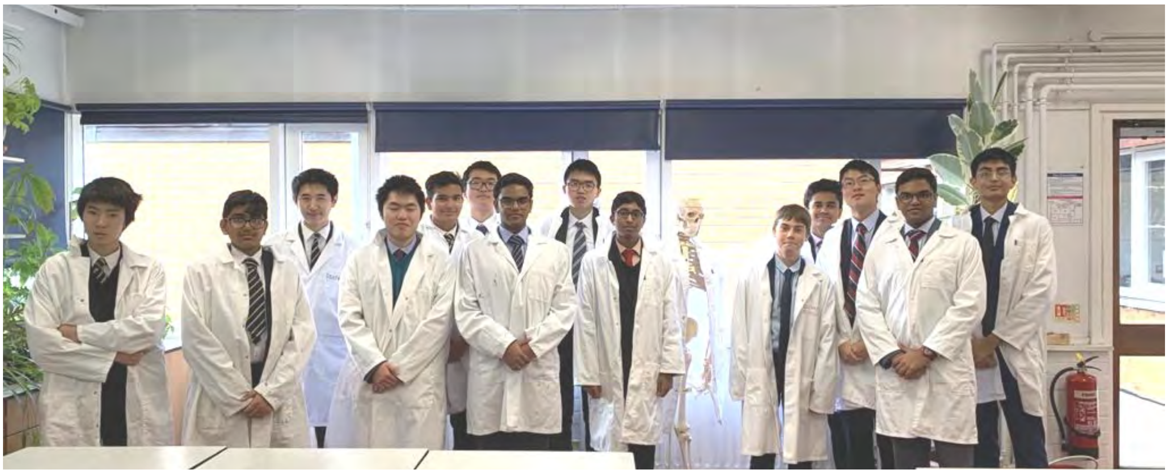
At university, I will be studying physics. Not only is it full of problem solving (which has always been interesting to me), but it also encompasses particle physics! I love the idea that we understand so little (pun not intended) about the tiny world of particles, despite their presence all around us.

Ray Wang
Editor
Engineering

Last year, when the science magazine was being founded, I jumped at the opportunity to be a part of this. I thought that this would give me a platform to share some of my knowledge in aviation with other students as well as helping me to develop my scientific writing skills. Having been a writer and editor for over a year now, I can say that I have not been disappointed. Not only do I learn a great deal while reading and editing others' articles, but also working in this community has introduced me to many more like minded students who I may not have otherwise have had the opportunity to collaborate with.

This year, I have applied to study engineering at university. Within this field, I'm particularly interested in mechanical and aerospace engineering, stemming from my lifelong interest in aviation. I've always been fascinated by the evolution of technology in aircraft development as aircraft as a vehicle have really not been around for too long (only one hundred years or so) and in that short period of time what has been achieved in some areas has been truly astounding. In the years to come, engineering is set to be a really exciting field as we strive to find solutions to help towards mitigating climate change. Being able to apply scientific principles in new ways to overcome some of humanity's greatest challenges is what engineering is all about and it is this that draws me to study engineering further at university.

THE CHIEF EDITOR: REFLECTIONS ON ISSUES 1-4



Issue 1 and 2's Team

Issue 3's Team

I could never have dreamt that the Wilson's Intrigue community could be where it is now. From what started off as a venture with 5 editors and 15 writers in Issue 1, the magazine now has a community of over 50 active members from years 11 to 13, between both the STEM and Humanities division of the Wilson's Intrigue. The images above serve to illustrate this growth. I am also pleased to say that with the inclusion of this publication, the current STEM editorial team has published 4 issues over the course of 2 academic years, persevering through the three national lockdowns and attending virtual meetings in their spare time. It has truly been a pleasure to witness the evolution of the magazine, not just in terms of growth, but by the progressive iteration of designs of former issues, finding innovative ways to present scientific concepts to our audience.

I would like to take this opportunity to personally thank my team of editors (Utkarsh, David, Harsh, Michael, Neo, Ray and Divy) who have been with me and supported my ideas every step of the way, all the writers who have been part of the Wilson's Intrigue through your active engagement in meetings and we would not have a magazine at all without your involvement. I would also like to thank all the subject specialist teachers acknowledged at the start of every issue for giving up their time outside of lessons, to assess the scientific accuracy of the articles and providing additional support to writers alongside the editors. Lastly, I want to thank Mr Englefield who initially gave me advice on how to make my idea a reality, Dr Whiting for inspiring me to undertake such an endeavour and making sure I do not overwork myself in the process and Mr Lissimore for giving the team the opportunity to publish the magazine and for his meticulous proofreading of each issue.

I want to conclude this section by wishing all the best of luck to the new STEM editorial team: Adi Jain, Aditya Chougule, Atharva Narkhede, Mann Patira and Divy Dayal and also to our sister organisation—the Humanities division of the Wilson's Intrigue, which shares all the same aims and values as us.

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