THE WILSON'S INTRIGUE

Issue 3: Friday 16th October 2020

BIO-CHEMISTRY
Cancer-killing Viruses

COMPUTER SCIENCE
Artificial Creativity

ENGINEERING
The Ground Effect

PHYSICS
Asteroid Mining

Introduction

Despite finding ourselves in the midst of a global pandemic, the science magazine team have been working arduously in the background to bring you another set of STEM topics covering experimental anti-depressants to quantum mechanics. The whole team is very proud of this collection and would like to welcome you to the third issue of The Wilson's Intrigue, written by students for the students.

We especially hope you will enjoy the new innovative design of the magazine, which you can expect to see in upcoming issues.

Our Mission

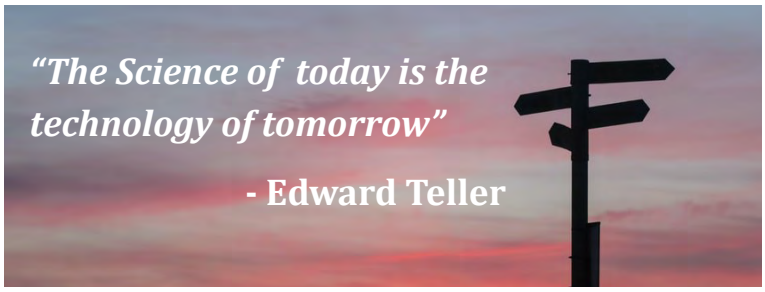
- Expand your knowledge
- Contribute to the Wilson's community
- Make complicated parts of science more accessible
- Popularise science and make it more interesting
- Inspire creativity through wider research

Acknowledgments

Thank you to Mr Lissimore and Dr Whiting, whose continued advice and support is very helpful in running the Science magazine. Thank you also to Mr Carew-Robinson, Miss Ip and Miss Roberts for their help in confirming the scientific accuracy of the articles.

And, of course, thank you to all of the brilliant writers and editors that have contributed to the magazine.

If you would like to write for the magazine and join a like-minded group of science and engineering enthusiasts, please email me (Devanandh) at *murugesand@wilsonsschool.sutton.sch.uk* for more information.



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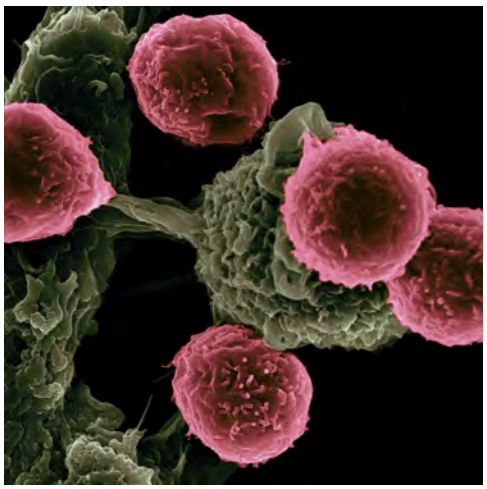

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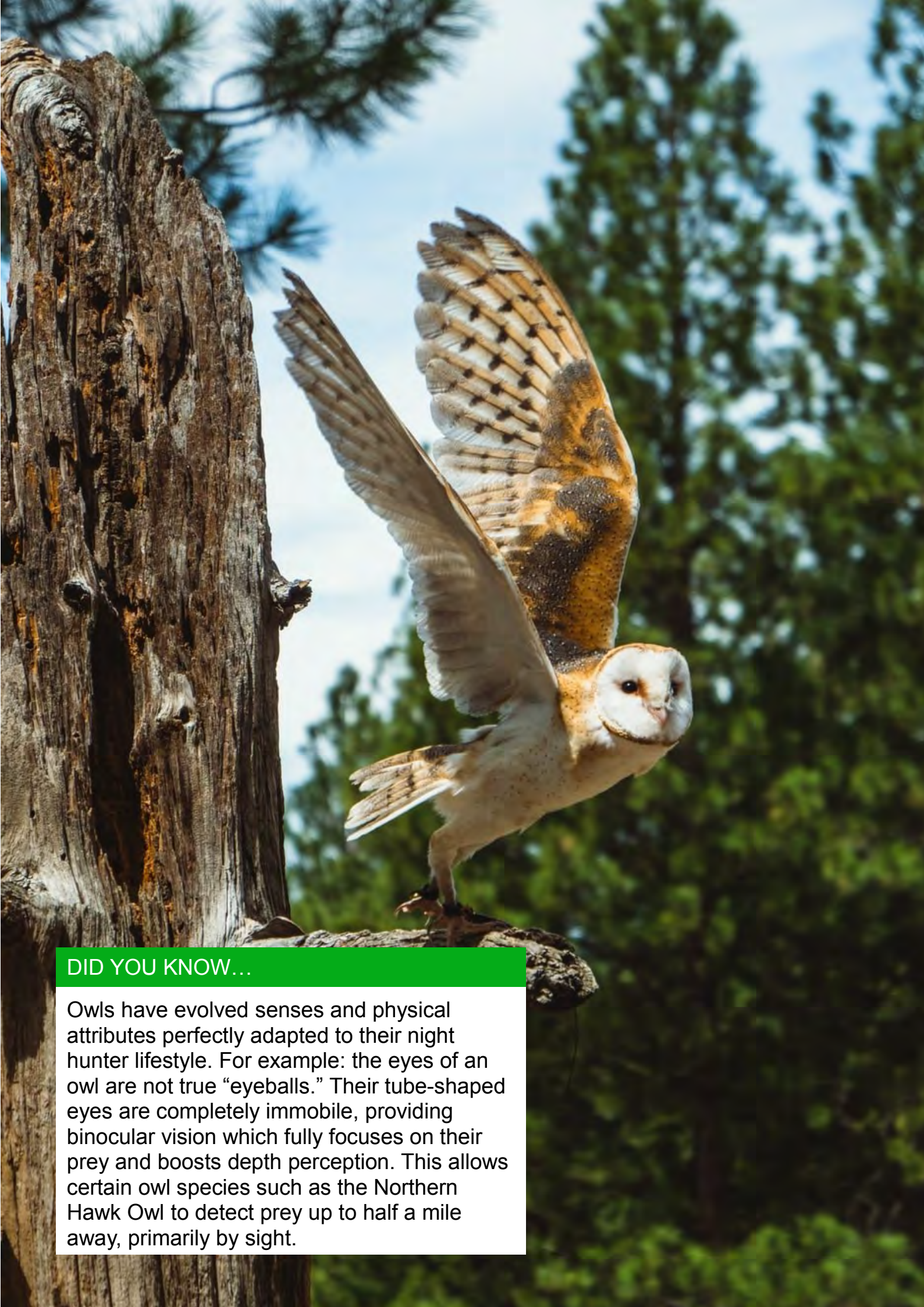

DID YOU KNOW…

Owls have evolved senses and physical attributes perfectly adapted to their night hunter lifestyle. For example: the eyes of an owl are not true “eyeballs.” Their tube-shaped eyes are completely immobile, providing binocular vision which fully focuses on their prey and boosts depth perception. This allows certain owl species such as the Northern Hawk Owl to detect prey up to half a mile away, primarily by sight.

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Esketamine for Depression: A Viable Treatment Option?

Is esketamine an effective treatment for depression ?

Anussan Nadarasa (Y13)

Depression is a leading cause of disability worldwide and one of the most prevalent mental health disorders, affecting more than 264 million people[1]. Individuals suffering from depression typically experience a range of both psychological and physical symptoms, such as despondency, disturbed sleep and the avoidance of social interaction. The causes of depression are diverse and can include stressful events, bereavement, genetics, serious illness and substance abuse[2]. Yet, all of these result in changes in both the brain and its chemical balance.

It may therefore be possible to determine the chemical cause of the symptoms of depression through examination of the brain. Through developments in brain imaging, it has been discovered that sufferers of depression frequently have a smaller hippocampus than those of non-sufferers. A smaller hippocampus has fewer serotonin receptors, thus less serotonin can bind to the receptors per unit time. Since serotonin is a neurotransmitter that allows communication across neural circuits that connect the different regions of the brain that are involved in processing emotions, the smaller hippocampus may be why sufferers tend to avoid social interaction. A key factor in the reduced size of the hippocampus may be stress, since stress has been shown to suppress the production of new neurons in the hippocampus and this hindered production may be the cause of low mood.

In order to relieve such symptoms, antidepressants may be used, with adjunctive psychological therapy. Antidepressants, in general, work by increasing the concentration of neurotransmitters, such as serotonin in the synapses, and also by stimulating the growth of neurones in the hippocampus in order to improve mood. However, when these two treatments are not successful in relieving the symptoms of depression, a predicament is reached. Thus, it is for the individuals who have been unresponsive to other treatments that the use of esketamine could be considered.

The Solution

Esketamine functions via a novel mechanism of action[3]. Intended for intranasal administration, esketamine is a non-competitive glutamate N-methyl-D-aspartate (NMDA) receptor antagonist[4]. In other words, esketamine blocks NMDA receptors, preventing glutamate from binding to them, thus it also prevents the activation of the NMDA receptors. Glutamate is the major excitatory neurotransmitter in the central nervous system[5], hence it allows for a higher degree of communication between neurones. However, esketamine disrupts glutamate signalling. This counterintuitive mechanism of action can be explained, though. NMDA receptors are unable to immediately respond to a glutamate signal, since they are blocked by a magnesium ion. Thus, a different type of glutamate receptor, AMPA receptors, help to remove the magnesium blockage that prevents the NMDA receptors from being bound to. Therefore, glutamate can, under normal conditions, now bind to the NMDA receptors. However, by blocking the NMDA receptors, esketamine causes the disinhibition of inhibitory GABA, which, under the influence of activated NMDA receptors, would normally downregulate the glutamate signal . Since ketamine prevents the activation of NMDA receptors and so prevents the regulatory effect of GABA, it causes a burst of glutamate to be released, which activates the AMPA receptors. It is this activation of AMPA that increases the signalling of neurotrophic factors, which supports both the rapid onset and

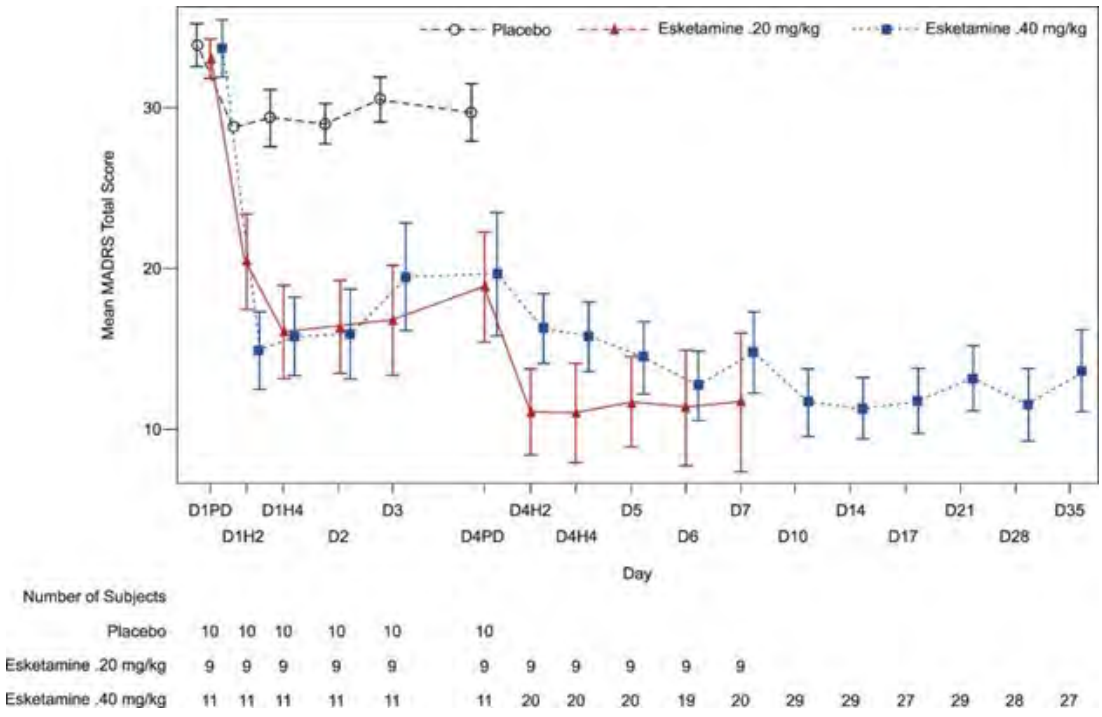


Figure 1: Mean Montgomery–Åsberg Depression Rating Scale (MADRS) total score over time by dose[8]

the long term antidepressant effects of esketamine[6].

This rapid-acting drug[7] has been clinically trialled in both the USA and the UK. For instance, one double-blind, double-randomized, placebo-controlled study[8] found that the improvement in depressive symptoms, as measured by the reduction in the Montgomery–Åsberg Depression Rating Scale (MADRS) score, was significantly greater in both esketamine groups compared with the placebo group, 24 hours after treatment. As illustrated in the graph of mean MADRS total score over time, from the initial does on day 1 to day 35 (Figure 1), esketamine showed rapid (within 2 hours) and strong antidepressant effects at each dose tested.

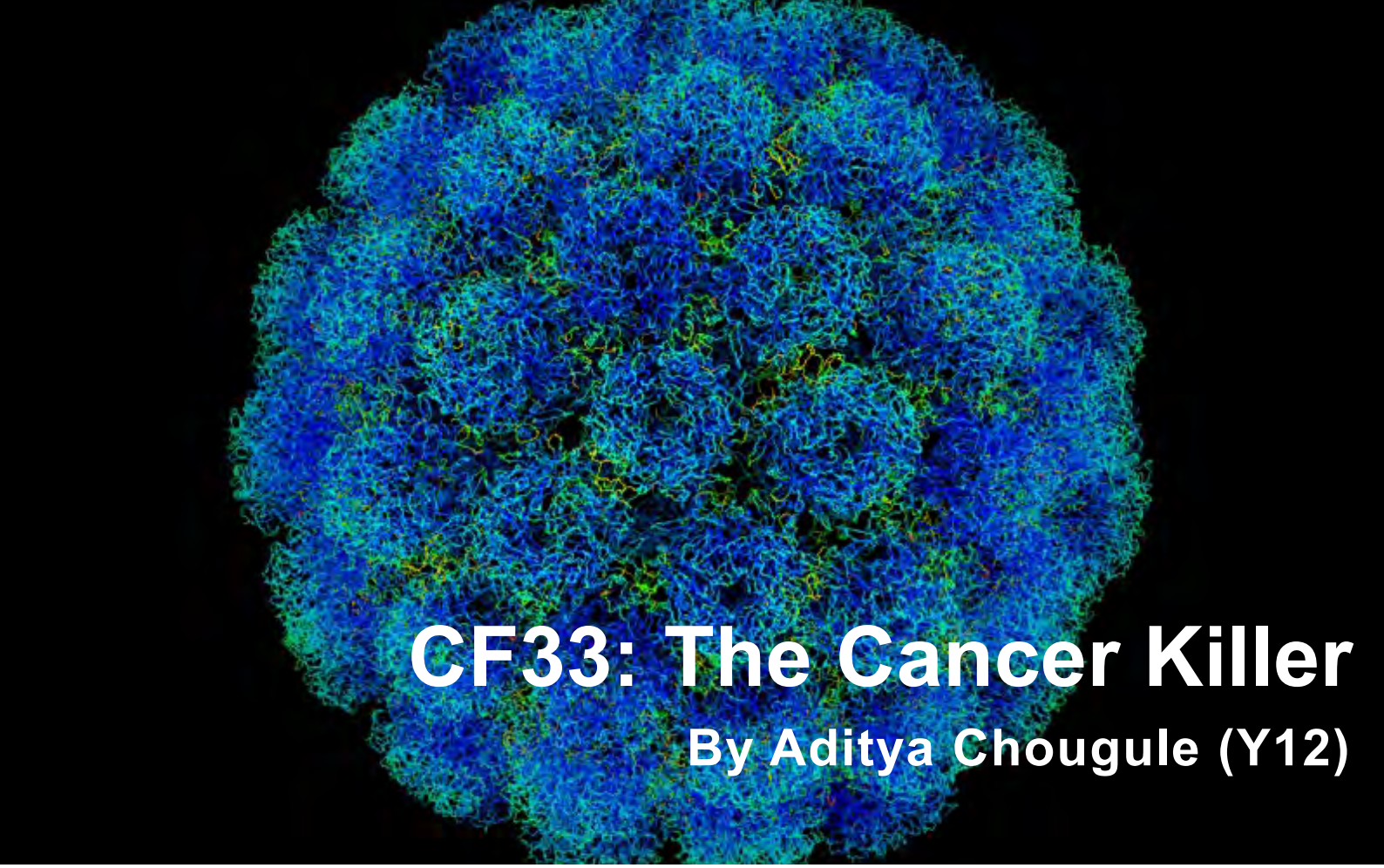
The study consisted of 30 men and women, aged between 18 and 64, who had been unresponsive to at least one antidepressant drug. On the first day of the treatment, the first dose was given and patients were randomly assigned in a 1:1:1 ratio to receive an IV infusion of 0.20 mg/kg or 0.40 mg/kg esketamine or placebo (0.9% saline solution) over 40 minutes.

On the fourth day, the participants received the same treatment and the same dose as on the first day. To ensure validity, patient demographics and their baseline psychiatric characteristics were generally balanced across all treatment groups. This study is simply one of many showing the potential benefit of esketamine.

Naturally, there is debate about the degree of benefit esketamine has as a medication, especially in light of safety risks, due to its psychedelic nature, and its cost, yet it has been shown to be significantly useful for non-responders to other depression treatments. In terms of safety risks, there is the potential for withdrawal symptoms and abuse of esketamine, which is the view of Professor Alan Schatzberg of the University of Stanford[9]. However, abuse of the substance can be combatted by the usage of a restricted distribution system, whereby a nasal esketamine spray is administered under the supervision of a medical professional in a certified clinical setting, with the spray not permitted to be taken home. This is the scheme that the FDA has implemented for this drug in the USA. In terms of withdrawal symptoms, researchers who analysed the data from the Physicians Withdrawal Checklist that was obtained from the phase 3 trial of this drug in the US, concluded that the evidence suggests that discontinuation of esketamine, following short- or long-term use of the nasal spray, is highly unlikely to be associated with any withdrawal symptoms [10].

In regards to the issue of cost, it is unlikely that the NHS, in its current state, will implement the use of esketamine into clinical practice. Based on the economic model put forward by the company who designed the nasal spray, an average course of therapy costs £10,554.25 [11]. The National Institute for Health and Care Excellence's appraisal committee suggested that the aforementioned cost may be an underestimate and the true value would be higher. They concluded that significant investment will be needed to adopt esketamine into clinical practice in the NHS and that, therefore, it is not a cost-effective use of NHS resources. Nevertheless, private patients and private clinics may be able to use the drug, should the treatment be approved later this year. Thus, despite the costs to the NHS, esketamine can successfully be used by private clinics and be adopted into the healthcare systems of different nations, as a rapid treatment for depression.

Edited by Harsh Sinha



CF33: The Cancer Killer

By Aditya Chougule (Y12)

Viruses can kill cancer. It seems absurd when you hear it for the first time, but these types of viruses (*oncolytic viruses*) have been tested in the laboratory since 1922, with the vaccinia (pox) virus being the first to demonstrate viral oncolysis. Vaccinia is a double-stranded DNA virus belonging to the Poxviridae family and it has a track record of safe use in millions of humans, as it was the active constituent of the vaccine that eradicated smallpox. Vaccinia has a short life cycle and spreads rapidly from cell to cell, but it does not integrate into the host's genome. Instead, it helps to destroy a broad range of tumour cell types through *cytolysis* and has the potential to act as both a *gene therapy* delivery vehicle and an oncolytic agent.

While oncolytic viruses can vary wildly from nature to the lab, they all have one thing in common: they preferentially infect and reproduce in cancer cells without harming healthy cells. Once they have infected the cancer cells, the viruses go through stages of the lytic cycle (see picture below) in order to replicate and eventually lyse out of the cell, destroying it in the process. The new infectious virus particles—virions—released help eradicate the remaining tumour. The dying cancer cell releases materials, such as tumour antigens, that allow the cancer to be recognised by the immune system,

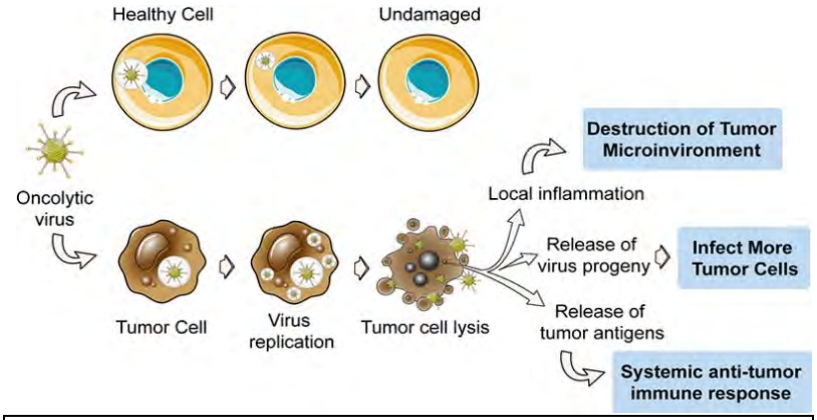


Figure 1 – How oncolytic viruses work

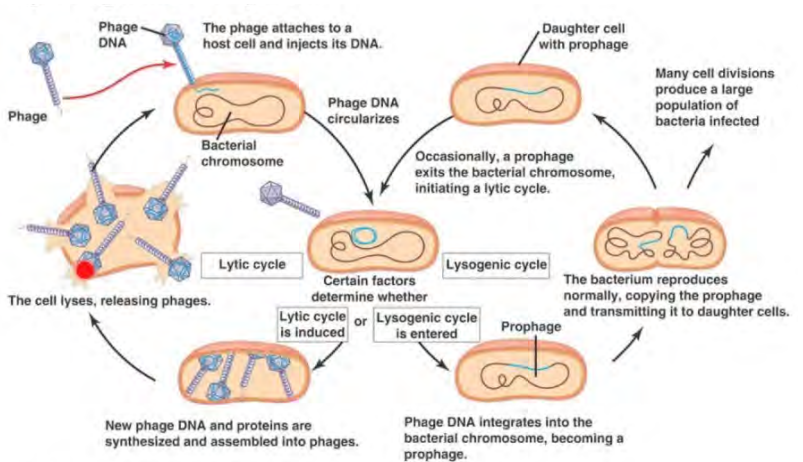


Figure 2 – The lytic and lysogenic viral life cycles

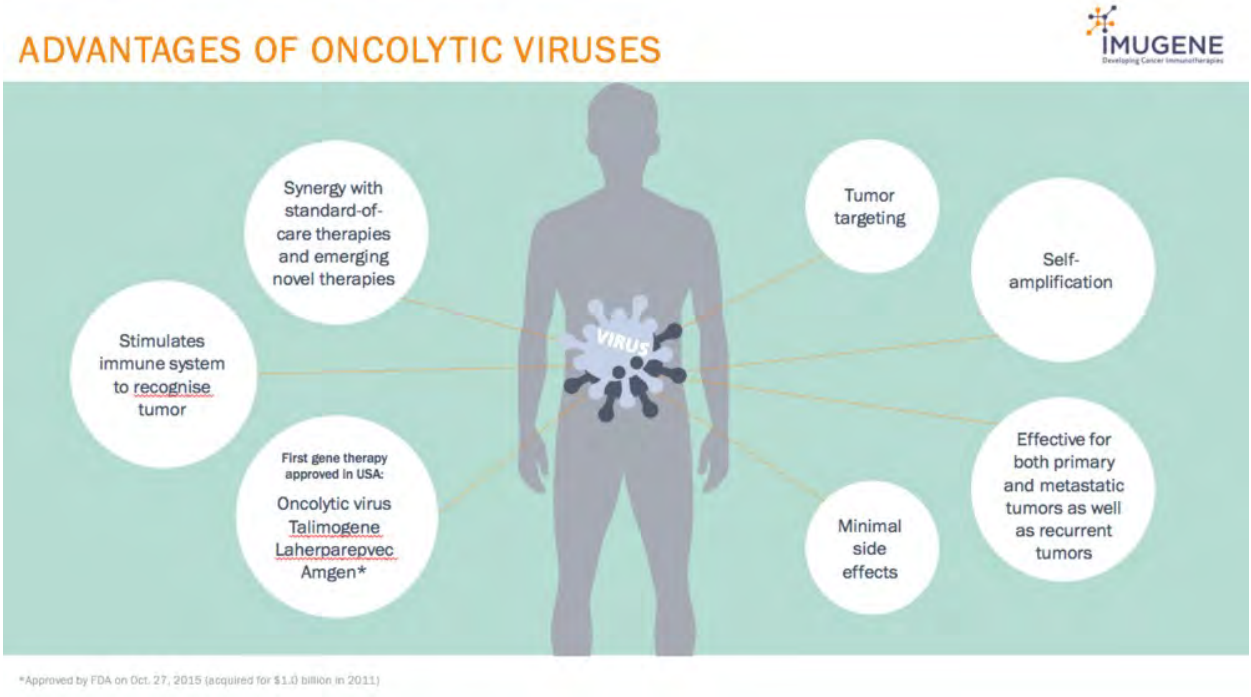
triggering an immune response against the tumour. In this way, oncolytic viruses can also be a form of immunotherapy, enhancing the body's immune system to respond more aggressively to mutated, hostile cells

This pretext is important in understanding the role of CF33—a *chimeric* vaccinia virus that is at the forefront of *oncolytic virus immunotherapy.* Developed by Professor Yuman Fong at the City of Hope Comprehensive Cancer Center in Los Angeles, California, CF33 combines the genomic sequences from multiple vaccinia virus strains to generate a new, safer and more potent virus.

Imugene, the clinical stage immuno-oncology company responsible for CF33, has announced plans to evaluate two different versions of CF33 oncolytic virus technology in separate Phase I clinical trials. One of these versions is called Vaxinia. Vaxinia mediates targeted radiotherapy by combining CF33 with the *Human Sodium-Iodide Symporter* (hNIS) gene, which enables imaging to track the virus *in-vivo*. Vaxinia is said to have shown encouraging activity in validated in-vivo models of pancreatic, colorectal, lung, colon and triple-negative breast cancers. The other version of CF33 is called CHECKVacc. This consists of a virus armed with both the hNIS and anti *PD-L1* genes, which enable enhancement of immunotherapy by inhibiting immune checkpoint proteins so that immune cells can better recognise and target the cancer cells. In preclinical studies conducted at City of Hope, CHECKVacc yielded favourable results against *triple-negative breast cancer* (TNBC) and according to a preliminary clinical development plan by Imugene, the CheckVacc and Vaxinia versions of the oncolytic virus are currently in phase 1 clinical trials, with results still pending.

Oncolytic virus immunotherapy is a young but ground-breaking field of oncology and the research taking place now will have an extraordinary impact on those suffering from various types of cancer in the coming decade. 1 in 2 people in the UK born after 1960 will be diagnosed with some form of cancer during their lifetime: it's clear why research such as this is vital.

Edited by Michael Lowe



Coronaviruses: SARS, Covid-19 and the Responses

By Daniel Wan (Y13)

This article was written in February this year, and as a result, is not up to date. However, we have kept it as it is an interesting read, and many of the points raised about the response to SARS and Covid-19 are still relevant today.

A brief overview of Covid-19:

Since the World Health Organisation (WHO) was first informed on New Year's Eve in 2019 of atypical cases of pneumonia that would later be identified as coronavirus disease (COVID) in Wuhan, Hubei Province, China (PRC), the spread of the responsible pathogen SARS-CoV-2[1] has received much attention globally, and on the 30th of January 2020, the outbreak was deemed a "Public Health Emergency of International Concern" by the WHO. As of 23 February 2020, 2,462 people have died so far from the respiratory infection, and there have been 78,810 confirmed cases across 33 countries and territories - numbers which will undoubtedly rise.

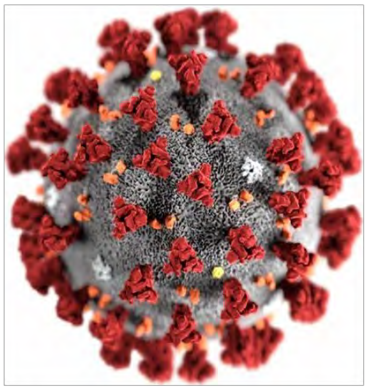


Figure 1 - An illustration of the SARS-CoV-2 virion

With the worrying spread of the outbreak, many comparisons have been made with the 2002-3 Severe Acute Respiratory Syndrome (SARS) outbreak, one of the first major outbreaks of the 21st Century. There are several similarities between the two diseases: both were the result of a coronavirus causing respiratory problems; both originated in China; most deaths were from people over 60, many with pre-existing health conditions;

> *"We are facing a human crisis unlike any we have experienced ...and our social fabric and cohesion is under stress."*
>
> **- UN Deputy-Secretary-General Amina J. Mohammed**

and it is believed that, like SARS, Covid-19 is a zoonotic disease[2]—a disease passed from non-human animals to humans . On the other hand, there are also several important distinctions to be made between the two.

Comparing the Diseases

SARS was first reported in November 2002 in Guangdong Province in South East China. By the end of 2003, the virus had infected 8096 people and killed 774, with the majority of deaths occurring within China and Hong Kong. However, the epidemic burnt itself out, and by July 2003, WHO announced that it had been contained[3].

In comparison to SARS, Covid-19 has infected a much greater number; some studies estimate each individual with the virus could, on average, infect 2.6 people . This has been attributed to the longer incubation period for Covid-19, meaning that the time between being exposed to the virus and the onset of symptoms is greater (14 days compared to the 2-7 of SARS), as well as the fact that people infected can still be contagious during the incubation period. In addition, Covid-19 also has a lower fatality ratio, currently recorded at 3.03% in contrast to 9.56% in SARS. Consequently, SARS was arguably much more severe in its symptoms, but the shorter incubation period, combined with the fact that its spread was only possible once symptoms began, made it far easier to contain and trace. Simply put, the nature of Covid-19 makes containment much more difficult.

The Response to SARS

Perhaps more importantly, how do the responses to each of the outbreaks compare? During the SARS outbreak, the People's Republic of China came under heavy criticism for its attempts to

cover it up. As late as January 2003, an official government statement was released, denying that there was an epidemic, while reporting of the disease was suppressed. Even when the virus was acknowledged in February, the WHO team was barred from travelling to Guangdong Province to observe the situation as it unfolded.

Its true extent was not revealed until April, when the Chinese government announced that it was giving top priority to the outbreak, and promised full disclosure, settling aside emergency funds for dealing with SARS and future epidemics. At this point, the virus had spread to several countries, including Canada and Singapore, the first of which was taken completely by surprise at the virus' arrival, and killed hundreds. Regardless, the movement towards transparency was important in facilitating international collaboration in studying the SARS virus to the point where a vaccine was prepared for trials, although these were not used. By May, the frequency of cases had decreased as the virus appeared to die out, and was concluded by July. The first major epidemic of the 21st century had ended.

The Response to COVID-19 - an improvement?

The failure of the Chinese government to take effective measures and inform the international community was arguably the most notable element of the handling of the SARS outbreak. The cover up came at a huge cost to both human life and to China's global standing, as earlier quarantine measures and the international sharing of information would have led to fewer lives lost. Consequently, the response to the emergence of a new type of flu in Wuhan has been ostensibly much more transparent and rapid: by early January, the responsible pathogen was identified as a coronavirus and the genome shared, the deployment of military personnel, rapid hospital construction[4] and extensive quarantine measures have been introduced - namely the lockdown of over 50 million people in Hubei Province. The global spread of the disease has led to other countries implementing their own smaller-scale quarantines of people who may have been exposed to the pathogen, and issuing widely-accessible advice about it. WHO proposes that $675 million would be needed for a global response plan, and it seems that the world is far more prepared to deal with the disease.

The implementation of measures on such a scale has led to the questioning of their effectiveness. The lockdown of the city of Wuhan was an impressive feat, let alone its extension to the entirety of Hubei Province, and when it was first introduced, it was described by a WHO spokesperson as "a very important indication of the commitment to contain the epidemic in the place where it is most concentrated." However, whilst the lockdown has limited the spread of the virus to other parts of China, there have nonetheless been reports of potentially preventable deaths due to the quarantine restrictions and shortages of medical supplies within the region. Accounts describing 7 hour waiting times to enter hospitals simply to receive checks demonstrate the extent to which the medical services have been stretched, but perhaps there is simply not much more they can do.

The response to Covid-19 in China has been a showcase on how an authoritarian regime can handle such a situation. Indeed, a quarantine of that scale would be nearly impossible to accomplish in a Western nation, as would the construction of a 1,000 bed hospital in six days[4]. In spite of this, there has not been complete transparency either, primarily illustrated in the death of Dr Li Wenliang, a doctor who attempted to warn people about the coronavirus, and was investigated for rumour-mongering, subsequently succumbing to the disease himself. This event sparked outrage across China not seen before. The balance of freedom of speech and controlling rumours is a difficult act, especially for a nation such as China .

Lessons have clearly been learnt from the SARS epidemic, and in spite of poor handling or overextension in certain cases, the PRC's response to the Covid-19 outbreak has been much more transparent and effective, if possibly excessive in some aspects. However, the nature of Covid-19 blurs such a comparison, with containment being more difficult, and the on-going outbreak has infected and killed more people than SARS. Ultimately, much remains to be learnt about coronavirus diseases and how best they can be responded to, and that optimal response certainly won't be a cover-up.

Edited by Divy Dayal

Hallucinations and Charles Bonnet Syndrome: The Phenomenon of Seeing with the Mind

By Ken Li (Y13)

Hallucinations, defined as "a sensory perception in the absence of such corresponding external stimuli", manifest themselves in many different forms and can occur in any sense. These may be visual, auditory, olfactory, proprioceptive, etc. However, a particularly interesting focus within this vast set is a condition known as Charles Bonnet Syndrome (CBS), a form of hallucination in visually impaired people, which has been especially neglected in terms of both acknowledgement and research.

It is estimated that approximately 285 million people are visually impaired worldwide, with 39 million being totally blind. Roughly 1 in 10 people get visual hallucinations which could be categorised under Charles Bonnet Syndrome, but only 1% of the people acknowledge them with the rest afraid of being labelled by others as insane should they reveal their plight. Nonetheless, all those affected by the condition will commonly experience hallucinations that come and go in a flash throughout their lifetime, and can manifest themselves in a broad spectrum of ways, ranging from the positively terrifying to the positively hilarious.

Charles Bonnet Syndrome, contrary to what one may think, does not originate from Charles Bonnet himself having the hallucinations, but rather his grandfather. Having had cataract surgery, and with extremely poor vision, his grandfather first described his condition to Bonnet in 1759. At one point for example, he saw a handkerchief in mid-air, with four orange circles; then he saw various objects in mid-air, including wheels, buildings and animals. Whilst these could clearly be recognised as hallucinations, given their sheer implausibility, other visions were not as apparent to him as being hallucinations, as they occurred in the context of his situation. One particular hallucination, for instance, involved a visit by one his granddaughters, who upon approach prompted him to exclaim "who are all these handsome men with you?" at which point he was reminded that there was no-one with the granddaughter, and the hallucinatory images of the accompanying men subsequently vanished.

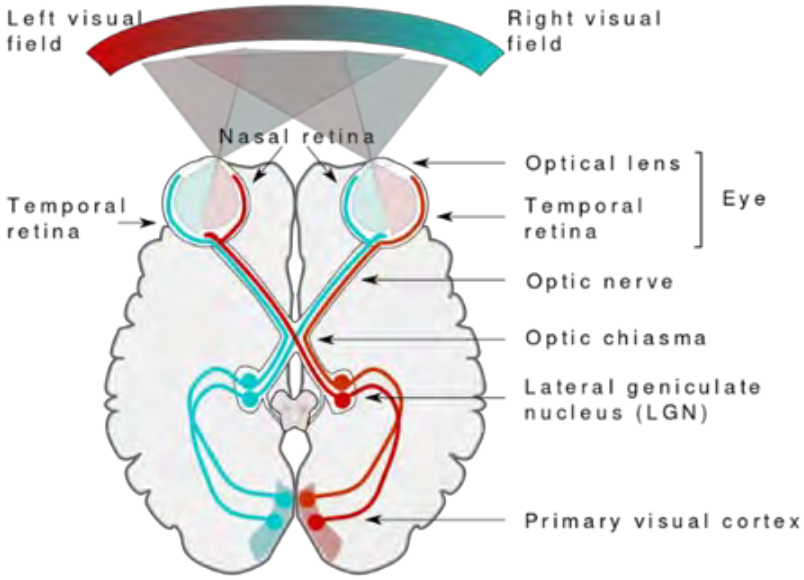


Figure 1— Magnocellular Cell

Oliver Sacks, the prominent neurologist, has described plentiful intriguing cases of Charles Bonnet syndrome of his own too. One particular patient describes a hallucination while she was in a restaurant. When she saw a man in a striped shirt turn around to face her and simultaneously divide into 6 different figures, each beginning to walk towards her. Similar other hallucinations had also plagued this patient, such as being in a car and seeing the road divide into 4 different roads, and feeling as if she was going up all 4 at once. Another of his patients, an elderly woman blind from macular degeneration for 5 years and living in a nursing home experiences hallucinations of a less frightening, albeit equally bizarre. For example, on one day she would see "people in eastern dress, walking up and down stairs; a man who turns towards her and smiles, but with large distorted teeth on one side

of the mouth; a white building, covered in snow, with a horse dragging the snow away". Scenes change drastically too: instead of these vivid images sometimes, rather alarmingly for her, she would hallucinate pink and blue squares on the floor beneath her feet, which would appear to rise up towards the ceiling [2].

So what is the biology behind this strange phenomenon? Why do these people consciously see images and events that would be more typical of a dream? Firstly, as mentioned above, Charles Bonnet syndrome occurs predominantly in people whose vision is either partially or fully impaired. When we see, coloured light incident on the cone cells in the retina activate certain proteins (photopsins) which trigger a phototransduction cascade, leading to the firing of an action potential down the cell, into the neighbouring bipolar neurone and into the optic nerve, thus generating an electrical impulse down the nerve and into the brain. This is via a visual pathway, where the electrical impulse passes along the optic tract, past the optic chiasma where the optic tracts from the left and right eyes cross over, and terminate at the lateral geniculate nucleus.

They then pass through the parvocellular layers of this structure, before arriving at the primary visual cortex. Different parts of the visual cortex, such as the fusiform gyrus or the calcarine sulcus[5] process the impulses to allow us to see a coloured image.

The most common cause of sight loss (which medicates the onset of Charles Bonnet syndrome), macular degeneration, affects the cone cells due to gradual age related breakdowns of these cells. These are concentrated in the fovea in the macula, located in the centre of the eye, and their absence prevents the electric impulses from being sent down the optic nerves to the brain. The neurones in the visual pathways in the brain, leading to the colour processing areas, are therefore deprived of any electrical stimulation.

Therefore these neurons become hyperactive and begin firing spontaneously, leading to the vivid and coloured hallucinations that people with Charles Bonnet syndrome see.

Why is it that some patients see terrifying visions during their hallucinations, whereas others get weirder, sometimes even hilarious ones? The key to this question is simply the sheer complexity and the uniqueness of each individual's brain. We all experience different events during our lifetime, see different things and have different memory. Because of the phenomenon of synaptic plasticity, our neurons are constantly changing the nature of their synaptic connections with other neurons to store our unique experiences and memories for retrieval and encode them within our brain, so as a result, the wiring in our primary visual cortices are all different. Therefore, the spontaneous stimulations of neurones that cause coloured hallucinations from our primary visual cortex concern a variety of completely different pathways in different patients, thus creating a variety of completely different hallucinations.

As mentioned earlier, this is evidently still an area of neurology that requires much research, as we are still yet to fully understand the full nature of this syndrome. Recently however, the ability to use fMRI on patients as they are having their hallucinations has enabled rapid progression of knowledge in this area. This is through allowing scientists to view and analyse the electrically active parts of the brain during these brief episodes, and the resultant increased insight into Charles Bonnet Syndrome has consequently encouraged more people to open up about their condition. Because no, these people are not insane.

Edited by David Kuc

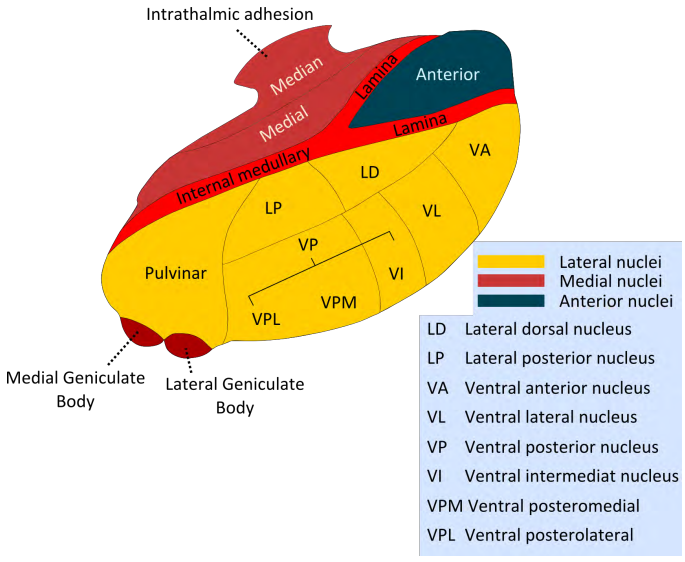


Figure 2— Thalamus

Cerebral Aneurysms: Complications and Treatments

By Koushikk Ayyappan (Y13)

An aneurysm is an *abnormal widening* [1] of weakened blood vessel - typically an artery - and is filled with blood. There are several types, but the most common is the *fusiform aneurysm* [2], which bulges on all sides of the vessel.

Typically a multifactorial condition, where some are uncontrollable, which could lead to rupture e.g. age, *hereditary causes* [4], hypertension and even mycosis (fungal infections) of arteries.

Although most aneurysms are asymptomatic, it does have a risk of rupture and catastrophic hemorrhage, increasing with size. This can lead to hypoxia (a lack of oxygen for cells, because the artery is occluded, preventing blood flow), followed by necrosis and eventually, an untimely death. In especially cerebral aneurysms, this prognosis is highlighted by the relatively low survival rate of 60%.

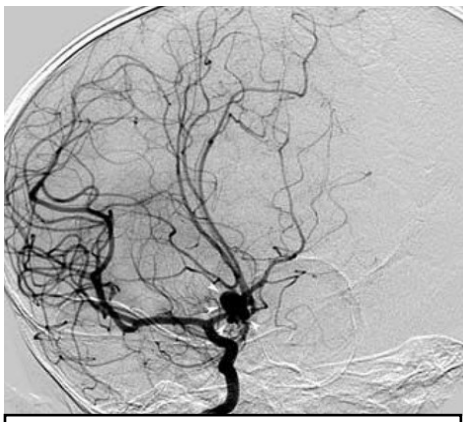


Figure 1 - A cerebral aneurysm

Treatment Options:

However, it would be a stretch to believe that if one is diagnosed with an aneurysm, recovery is impossible - especially due to the various treatment methods available, which can prevent damage pre-rupture. The exact type of treatment used depends on the aneurysm and patient.

The main surgical option would be microvascular clipping, during an open brain surgery, whereby the surgeon must clip the aneurysm on its neck via an applicator, to prevent its growth and eventual rupture. This is a difficult task, especially when considering the delicate vessels of the brain and even a minuscule error can lead to a stroke or haemorrhage (bleeding). As a result of technological advancements, the more frequently used procedure would be a platinum coil embolisation, performed by a neuroradiologist. A catheter is inserted via the femoral artery and threaded to the aneurysm's location. Detachable

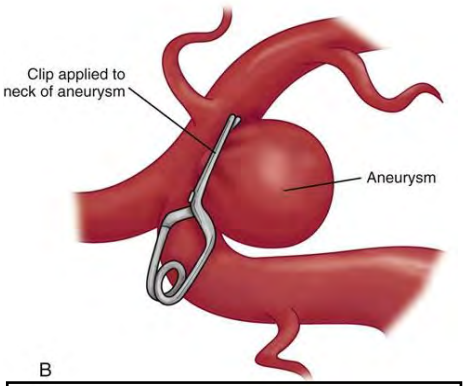
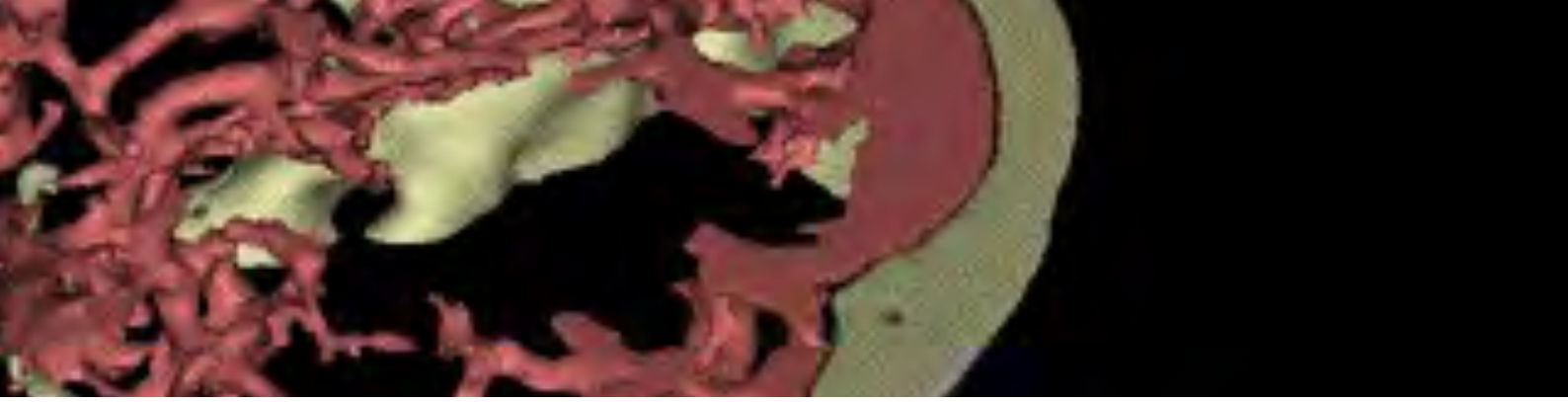


Figure 2 - Microvascular clipping

coils of wire are passed through the catheter and released into the space of the aneurysm, as shown on the right, reducing blood flow. The coil promotes blood clotting, sealing the aneurysm off. As fluoroscopy (a live X-ray) is used, the small coils of platinum will especially visible and aid the radiologist in the procedure, which has a much lower risk of casualty compared to surgery.

Another example of endovascular treatment would be the use of flow diversion devices e.g. a stent, inserted via an angioplasty (also used in the treatment for atherosclerosis), which would be placed into the artery to reduce any blood flow into the aneurysm. A vasodilator drug may also be used to expand the blood vessels in the affected area, allowing the balloon to travel more smoothly and quicker.



Complications:

Medical procedures almost never come risk-free, and each type of treatment carries both benefits and drawbacks.

If the surgeon fails to clip the aneurysm to a high standard, a subarachnoid hemorrhage can occur (bleeding between the brain and skull), due to a rupture, and a process called vasospasm can follow within the underperforming blood vessel due to persistent vasoconstriction of its smooth muscle layer. Pharmacological treatments can ease these symptoms, such as by using calcium channel-blocking drugs. A lack of calcium reduces the action potentials forming in the myocytes of the tunica media, and therefore reduces the rate of muscle contraction, inducing vasodilation and decreasing blood pressure. The possibility of an ischemic stroke is minimised as well, which is a common secondary effect of vasospasm.

This type of haemorrhage is often coupled with a permanent disability, and rehabilitative therapy may be required to regain lost function and cope with the increased difficulties in performing everyday tasks.

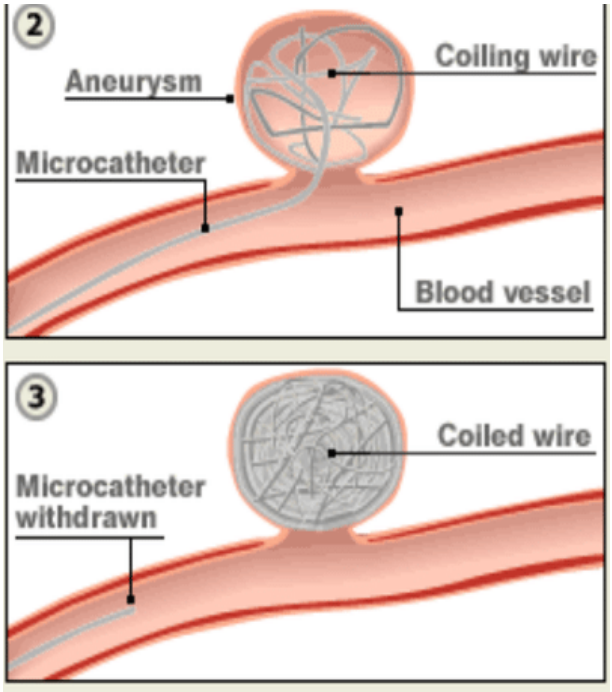


Figure 3 – Platinum coil embolisation

Moreover, another complication of a rupture could be hydrocephalus, which is the accumulation of cerebrospinal fluid (CSF) - the liquid surrounding our brain and the spinal cord. Since the blood from the hemorrhage can inhibit the circulation of CSF, despite the blood-cerebrospinal fluid barrier's attempts (which aims to separate CSF from the blood), increased pressures on the brain may ensue, which can damage tissues, and cause the expansion of brain cells.

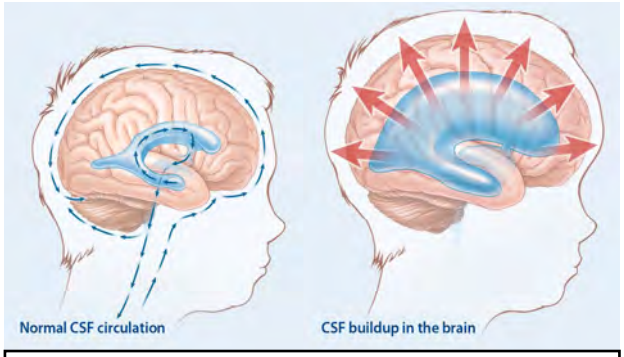


Figure 4 – Hydrocephalus: accumulation of CSF

Milder effects include pseudoaneurysms (false aneurysms) from coil embolisation, which occur when leaking blood collects in the surrounding tissue, as a result of a blood vessel wall being injured during the procedure. Moreover, heart, respiratory and kidney problems may arise during the recovery period (although this tends to occur more in the elderly), as well as inflammation where the catheter was inserted.

Despite the grim potential after-effects, it is important to be aware that the chances of these complications are extremely slim. An untreated aneurysm is much more likely to cause harm in the long term if it ruptures, and the doctor will always ensure that the patient makes an autonomous, informed decision on their preferred mode of treatment after discussing the risks and benefits.

Edited by Divy Dayal

Is Exon Skipping a Suitable Treatment for Duchenne Muscular Dystrophy?

By Shivank Khare (Y13)

Duchenne Muscular Dystrophy (DMD) is a severe type of muscular dystrophy that is an inherited degenerative condition that gradually causes muscles to weaken. The symptoms of this disorder are shown at a young age (around 4 years) and is more common in boys than girls since it is an X – linked recessive disorder. However, females who carry the defective gene may show mild symptoms. The severity of the symptoms for boys are extreme when they reach teenage years as they are unable to walk or even stand up[1] [3].

Duchenne muscular dystrophy is caused by the absence of dystrophin. Dystrophin is a protein that works by strengthening muscle fibres to prevent them from being damaged when contracting and relaxing. The dystrophin glycoprotein complex is part of the muscle membrane that is involved in preventing damage to the muscle fibres. However, when the membrane is damaged (as result of no dystrophin) then the muscle fibres release enzymes called creatine kinase. These proteins are essential for the energy required for muscle contraction. A way to test if a child has Duchenne muscular dystrophy is by testing the levels of kinase enzymes found in a blood sample since high levels of kinase enzymes often show muscles being damaged by muscle dystrophy[2].

Duchenne muscular dystrophy is caused by a mutation in the dystrophin gene - deletion of nucleotides within a gene causes the rest of the bases to be read incorrectly due to a frameshift. Furthermore, this leads to the ribosomes within the cells being unable to make dystrophin due to the genetic code for an incorrect protein. Since the cells are unable to make dystrophin, it causes the muscle fibres to become damaged and eventually die hence leading to progressive muscle weakness. Due to the degeneration of muscle fibres, it leads to difficulty standing and difficulty in most movements such as climbing stairs or sitting down [3].

The dystrophin gene is known to be the largest gene in our body with 79 exons. Due to it being a large gene it is more susceptible to mutations.

Exons are sequences of DNA that contain coding information for a protein. These are dispersed among introns in the gene which do not code for a protein and interrupt the sequence. Introns are removed from the sequence, otherwise a non functional protein would be made during translation. After removing introns, then the gene contains 79 exons. An analogy of exons would be pieces in a puzzle – if you were to remove some exons, then the sequence would still function, and the person would show mild symptoms. However, with DMD, the exons that are deleted prevent the remaining exons from being assembled correctly.This results in a non-functional dystrophin protein as both ends of the protein must work and hence leads to the symptoms of DMD[4].

A treatment for this is known as exon skipping. The therapeutic treatment approved by the FDA is known as Eteplirsen (which is made by Sarepta Therapeutics). Its main objective is to hybridise exon 51 in order to allow the machinery to skip it during mRNA transcription and still produce the desired protein due to the remaining exons being correctly assembled. In this case symptoms of Becker muscular dystrophy (less severe form of muscle dystrophy) would be shown as the dystrophin produced would be a lower quantity but be functional. Exon skipping works by masking the exon by molecules called antisense oligonucleotides (AON) near the DMD gene where one or more exons are removed. AONs are short nucleotides that can be used to mask the mutated exon. This then acts as an intron and is removed by splicing. This allows the reading frame to be read correctly and hence produces a small amount of functional dystrophin protein and allows the progression of the disease to be prolonged[5].

In order to prove that Eteplirsen can be used, clinical trials must be conducted. In one clinical trial, they used 30mg/kg/week of Eteplirsen per week which resulted in a 22.9% increase in dystrophin fibres. They decided to increase the dose to 50mg/kg/week which resulted to a mean 51.7% after 48 weeks from treatment. The FDA required to investigate further to validate these

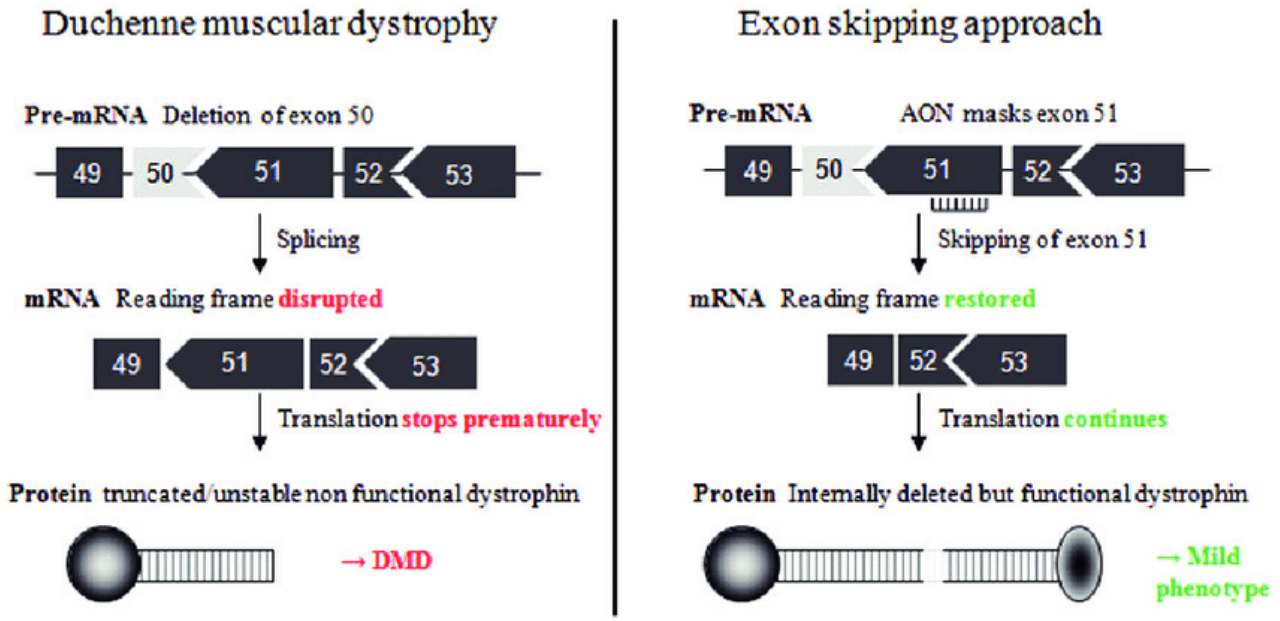


Figure 1— How exon skipping allows the production of functional dystrophin to treat DMD

results, so they took biopsies from 11 out of the 12 samples which revealed that they had 0.93% of dystrophin levels found in healthy individuals. Also, Eteplirsen was used in mouse models which revealed that small doses of dystrophin can lead to an increased chance of survival. However, 3 years into the clinical trials, two out of the 12 patients lost the ability to walk (ambulation). Despite this being an improvement from other experiments, the FDA didn't believe that Eteplirsen can be deemed sufficient effective. Further experiments aimed to prove that Eteplirsen would lead to increased life span for DMD patients but not all the patients receive the therapeutic benefit. Despite two patients losing the ability to walk, the other ten patients (with DMD) were functioning and walking better than previously and hence the FDA approved the use of Eteplirsen[6] [7].

Firstly, exon skipping is a revolutionary idea that I believe will be implemented more in the future. It shows promising signs as it allows dystrophin to be produced and hence allowing individuals with DMD to function better. Furthermore, DMD is a terminal illness and many people diagnosed with this disease do not surpass the age of 30 – hence the prolonging of the diseases that is achieved by this can be very beneficial. Eteplirsen allowed dystrophin to be produced but in smaller quantities, however, this leads on to Berker MD which isn't as severe as DMD and hence improved quality of life.

Also, this is an idea with great potential but some limitations – the same molecular patches may not work for different people. This is because different people with Duchenne MD may have different exons removed. E.g. Exon 51 skipping only accounts for 13% of DMD patients. This can make the procedure quite expensive and time consuming due to the need for finding different molecular patches (AONs). Moreover, as shown in the clinical experiments, not everyone benefited from it as 2 people lost the ability to walk hence there is a risk involved. The use of exon skipping is limited since it is a relatively new idea and further improvements are required to perfect it as it was initially overruled by FDA due to the safety concerns.

Overall, this idea needs further development to be applied to all exons and not just common ones such as Exon 51 skipping. However, having said that it improves the life of people with DMD and hence people should use this treatment if applicable because the benefits it has outweighs the risks.

Treating the Symptoms of MS: Is 'Medicinal Marijuana' the Answer?

By Tunmise Obilade (Y13)

Multiple sclerosis (MS) is an autoimmune disease which causes the immune system to essentially 'attack' the brain or spinal cord [1]. More specifically, it is known as a demyelinating disease because it damages the myelin sheath of neurones. This can inhibit their insulation causing signals to be lost and a range of problems to subsequently follow.

The exact reason why some people develop multiple sclerosis has not actually been proven however it is believed to be caused by a combination of environmental and genetic factors. MS is more common in regions with high Northern European populations and in people who live further from the equator (both with exceptions) [6]. This is thought to be due to lower vitamin D levels from a lack of sunlight exposure. [2] MS isn't inherited directly from parents however the chances of developing it increases if a relative has it, with a 2-3% chance of a child or sibling developing it from their parents/siblings[1] [2]. Gender also plays a role in the chances of developing MS as women are around 2-3 times more likely to develop MS[1]. Smoking also on average doubles one's chances of developing MS but the specific reasons for this are currently unknown[1]. Most importantly, viral infections are believed to be a possible trigger to the immune system, causing it to attack its own cells, leading to MS[3] [4] .However, no microbes or viral infections have been confirmed to do so[3].

A person with MS can suffer from almost any neurological symptom and they can be very unpredictable[1]. These symptoms follow two main trends which define which type of MS a person may have. These are either 'gradually worsening over time without periods of recovery' or 'episodes of sudden worsening that last a few days to months (called relapses)'[5]. The most common symptoms are autonomic, visual, motor, and sensory problems[6]. However, other symptoms include fatigue, vision problems, numbness and tingling, muscle spasms, stiffness and weakness, mobility problems[7]. More specific symptoms such as these are caused by lesions in specific places within the nervous system [8].

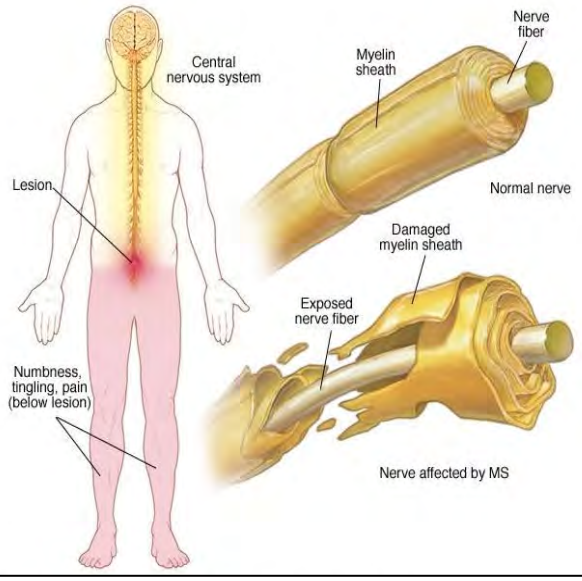


Figure 1 – A 'normal' nerve vs. the nerve of someone with MS

MS is difficult to diagnose as no single test can positively diagnosis it and it is unlikely to confirm MS with only 1 attack of MS-like symptoms. There are many tests that can be taken, some of which are outlined below:

Neurological examination – where a neurologist may look for nerve damage which may be presented as changes, abnormalities or weakness in motor and sensory functions [9].

MRI scan – which can highlight any damage or scarring of myelin sheath (used mostly to confirm suspicions of MS) [9].

Lumbar puncture – where a sample of your spinal fluid is removed by inserting a needle into the lower back which is useful because spinal fluid surrounds the brain and spinal cord and changes in the fluid can suggest problems with the nervous system. Once obtained, the sample is tested for antibodies and immune cells, which could suggest that your immune system has been fighting a disease in your spinal cord and brain. It is used mainly after initial scans and/or if symptoms are unusual [9].

All these tests above are used not only to diagnose MS, but also the type of MS a person may have.

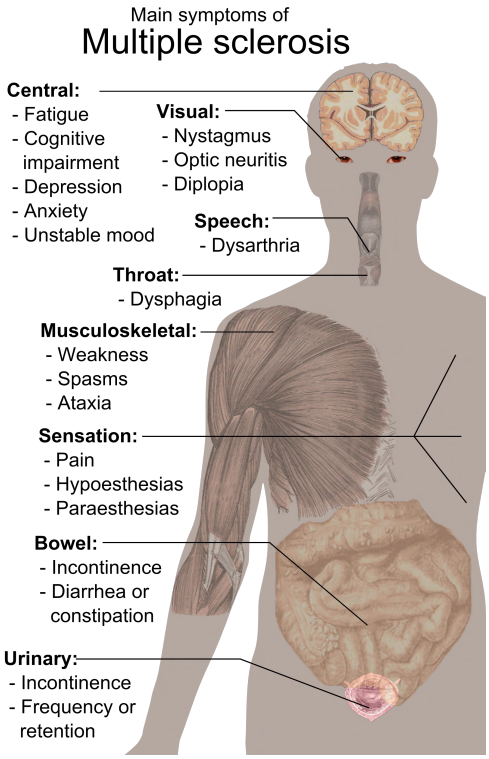


Figure 2— Common symptoms faced by Multiple Sclerosis sufferers.

Medicinal marijuana as a solution

Even today, there is no cure for MS, however there are many methods (such as medicinal marijuana) used to ease the most common symptoms such as severe pain and episodes. This is used mainly to control muscle spasms (spasticity) and pain[10]. The drug I will being exploring is 'Sativex' (the brand name for a drug called 'Nabiximols'), the only MS drug based on cannabis to get a license in the UK. It is a spray taken orally and contains two chemicals from the cannabis plant (cannabinoids) – an equal mix of tetrahydrocannabinol (THC) and cannabidiol (CBD). Most users start off with daily doses and gradually increase the dose until they experience the relief from symptoms (without exceeding the daily limit of 12 doses)[11]. More specifically, cannabis plants contain up to 40% CBD which has many beneficial effects e.g. its anti-inflammatory (reduces inflammation or swelling) and treat oxidative stress[12] (it defends you against oxidants which are reactive molecules that can cause disease and inflammation). It is also neuroprotective which is very useful for those with MS as it helps preserve the integrity of neurones and reduces the rate of neuronal loss. Medicinal marijuana is controversial due its advantages and disadvantages each bearing their own weight. One major advantage of medicinal marijuana is its endocannabinoid system (a complex cell-signaling system) which can promote neuroplasticity (how much the brain can change continuously throughout an individual's life) and maintain the immune system — despite its integrity being compromised in those with MS[11]. Another reason for the use of medicinal marijuana is that it is one of the few treatments for MS that efficiently eases pain. Others medical treatments that do are Lyrics, opiates and Neurontin, however these are all heavily sedated, limiting options for patients[10]. Furthermore, medicinal marijuana, unlike recreational marijuana, is heavily monitored with it being prescribed only to those who have tried and failed to cope with other treatment[10]. Additionally, if there is no substantial improvement after two weeks the treatment is terminated[10].

Despite this, there are some substantial disadvantages of medicinal marijuana. For example, users can experience mild hallucinations due to THC in the brain which also induces the feeling known as a 'high'. This can lead to an altered perception of reality and reduced motor skills. Additionally, there is the risk of addiction when taking marijuana. Although it is substantially less addictive than other drugs such as alcohol and nicotine, 10% of regular users still become dependent on it[15]. Everyone reacts differently to marijuana meaning it is not possible to tell how dependent someone may become on it. This causes issues when giving doses due to someone possibly having an addictive personality (traits that make an individual predisposed to developing addiction). It is also easy to gain a tolerance to marijuana meaning users need to take more to experience the same effects which can increase the chance of an overdose. This is believed to be a trigger to major health problems such as schizophrenia (although there are no conclusive results).

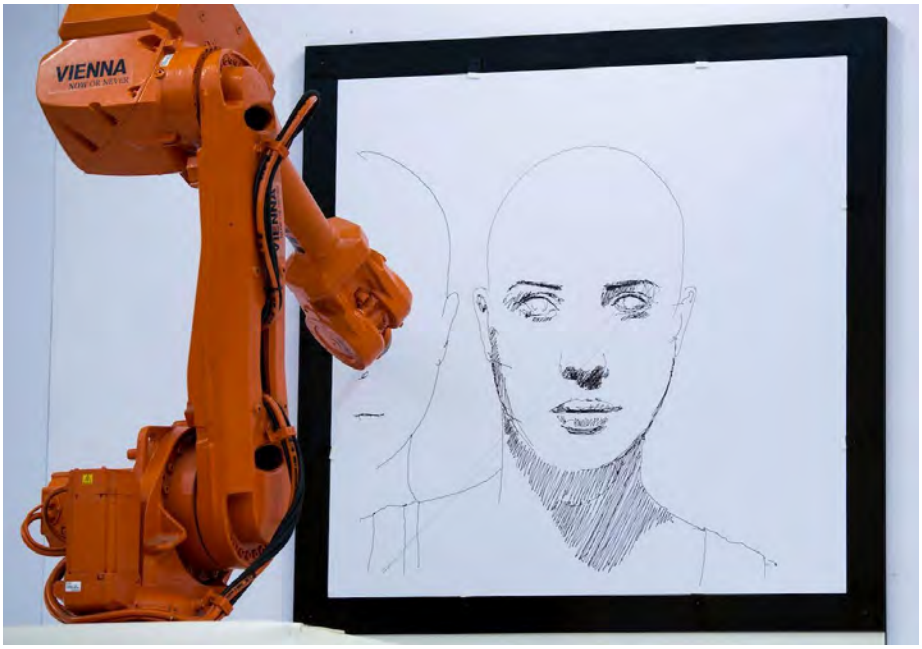
Overall, the idea of medicinal marijuana needs further research to form any fair judgement. However, there is no denying that marijuana does possess substances than have major health benefits that must not be dismissed due to the negative stigma surrounding its use. Under appropriate management by a governing body, marijuana has the potential to help alleviate symptoms from some of the most harmful and painful diseases in the world, including MS. The question is, at what cost?

DID YOU KNOW…

Obsolete computers and old electronics are valuable sources for copper, gold and silver if recycled; otherwise, these devices are a source of toxins and carcinogens such as cadmium, chromium, radioactive isotopes and mercury. If these chemicals are released into the environment, they could cause severe damage to human blood and kidneys, as well as the central and peripheral nervous systems.

"Our intelligence is what makes us human, and AI is an extension of that quality"

- **Yann LeCun**



An industrial robot that reproduces an art work of Austrian artist Alex Kiessling

Artificial Creativity

Can Artificial Intelligence replicate creativity?

Michael Oduyemi (Y13)

Since the creation of computers, people have been trying to replicate human intelligence in them.

However, there is one major aspect of human intelligence that is a significant challenge to replicate in AI systems – creativity. This is defined as the use of skill and imagination to produce something new.

In order to achieve artificial creativity, we need to first understand human creativity and then use that knowledge to develop a computer that is capable of human level creativity.

Artificial Creativity

Scientists have discovered three main types of creativity: combinational, exploratory and transformational.

Combinational creativity is the act of linking distinct ideas together in order to generate a new idea. Some examples of this are puns where two ideas are linked together in a funny way and analogies where one idea is explained by linking it to another idea.

AI faces two challenges when it comes to achieving combinational creativity: 1) linking ideas together and 2) coming up with a relevant new idea. AI has already achieved the first, which can be seen in data mining, where it is able to link data together and identify trends. An example of this was the identification of a new gene linked to Alzheimer's by comparing genes in mice and humans. The challenge now is to be able to generate new ideas. If that can be achieved, then we will be one step closer to achieving artificial creativity.

Exploratory creativity is the act of examining conceptual spaces [2] to generate new ideas that fit inside that style. This type of creativity is mostly seen in art and science. In art, paintings are often done to conform to a certain style e.g. impressionism or expressionism. The artists will be creative within a certain style and this will lead to new and unique paintings.

AI is already able to show this type of creativity. In fact, the majority of creative computers today are exploratory. An example of this can be seen through AARON [3] which is able to create original artistic paintings.

These paintings are exploratory because they are unpredictable but have the same style. One of the reasons why AARON was so successful was because Harold Cohen (a British born artists who was its creator) had domain-expertise [4]. This meant that the AI was programmed by someone knowledgeable in field of art so AARON was able to produce the right type of paintings.

Transformational creativity is the act of varying some of the rules of a conceptual space to create ideas that would otherwise be prevented. An example of this

could be changing the rules of a game e.g. allowing footballers to handle the ball. This will mean that a new game has been created which would not have been possible if the original rules of football were followed.

This type of creativity is where the least progress has been made. This is true for many reasons. One reason is that most AI programmers don't give their programs the ability to change the code (alter the conceptual space). This is because most AI programmers are more interested in exploring a particular conceptual space rather than the ways in which it can be altered. Another reason is because transformational creativity often results in ideas that are not useful.

What the future holds

There are two major challenges that are preventing the creation of AI which can successfully replicate all the types of creativity.

One challenge is domain expertise. Many AI programmers don't have domain expertise so are not able to create AI that produces the desired effect. For example, if Harold Cohen did not have knowledge about art, then AARON wouldn't have been able to create paintings of a particular style. Therefore, in order to make more progress towards artificial creativity, more programmers will need to have considerable domain expertise in the field that the AI will be focused on.

Another challenge is evaluation of ideas. As said before, transformational creativity can result in non-useful ideas. Therefore, AI needs to be able to recognise poor ideas and get rid of them or change them by using an evaluation mechanism. However, this is a significant challenge to create as the ideas would need evaluation that is specific to the conceptual space. If the conceptual space has been altered, then new evaluative mechanisms would need to be created.

Once these two main challenges are addressed, AI will be able to be truly creative.

Edited by David Kuc

Notes

1. Functional magnetic resonance imaging which measures brain activity by detecting changes associated with blood flow
2. Previously existing and culturally accepted style of thinking
3. A computer program written by artist Harold Cohen
4. Knowledge in a particular field

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Painting created by AARON

Virtual Private Networks (VPNs)

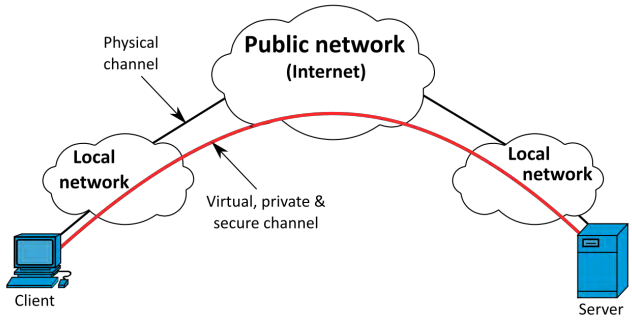
By David Kuc (Y13)

The term “network” refers to the hardware and software connecting multiple devices. The topology or physical network is the hardware (cables and routers) connecting the devices. A virtual network is the software that overlays the hardware of a network, or the programming that controls the routers/hubs/switches/ etc.

A public network is a network which, as its name suggests, can be accessed by anyone while a private network is secured so that only certain users can access it. For example, the internet is a public network while home networks are usually private. In order to send information via a private network, you need to first be a part of it.

A virtual private network (VPN) is therefore where a software link is set up between devices which can only be accessed by these devices. Because this link is software based, it can extend across several other networks, enabling it to reach anywhere you could reach publicly.

A proxy server is a server which acts on your behalf, so if you were to search something with a proxy enabled, the proxy server would send the request on your behalf and send the response back to you, so that only the proxy server knew you were involved.



Now with this information, you might assume that downloadable or extension VPNs simply provide a secure connection to the final server. However, you would be mistaken; public servers don’t usually have functionality to allow for the setting up of VPN connections, so rather, online VPN services are actually not just VPNs - they act as both a proxy and a VPN. A VPN is set up between you and the server, so that no one else can track that the request came from you, and then the VPN redirects your request as if it were its own and returns the result back to you.

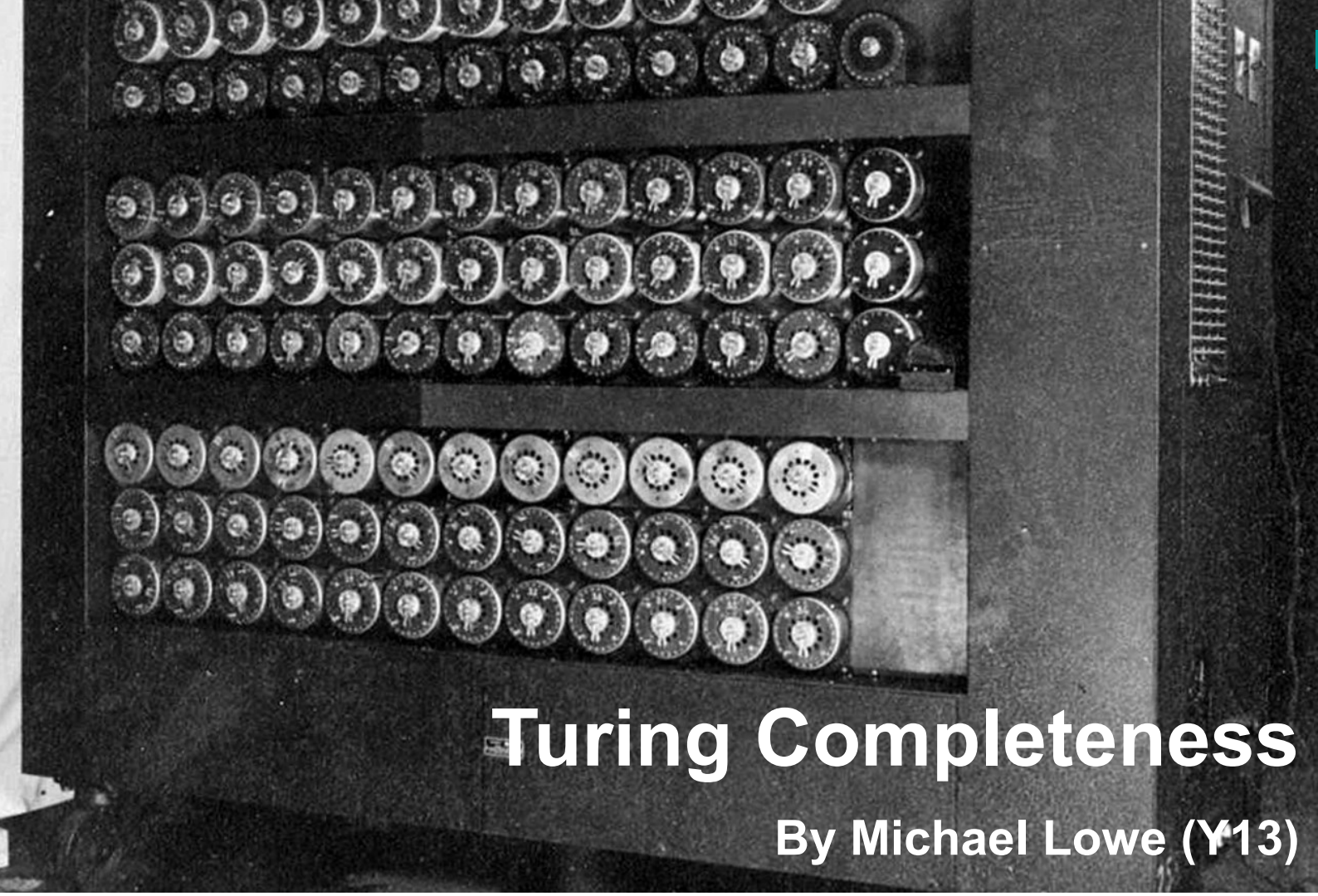
This is useful as your internet service provider and anyone monitoring you will only see an encrypted connection between you and this VPN service — they won’t actually know what you are connecting to so if your government or local network is blocking certain content, but not the VPN, then you can access it without them knowing or being able to stop you. However, this does carry large risks.

Some VPNs are not reliable, and the data between you and the final server is not always encrypted, which means that the VPN can steal your details and store sensitive information like bank details. I would therefore not recommend using a VPN you have reason not to trust for online banking.

Also, there is the issue of identity theft. The proxies could sell your information on to other companies e.g. ad agencies or law enforcement, which would be a severe breach of your data, and would defeat the purpose of you using the VPN in the first place.

Finally, remember that companies that host VPNs are running a business, and therefore need to make money in some way. Most do this by creating premium access accounts, which is relatively harmless (you will just need to accept slower internet speeds on a free account). Some VPN services make their money in the ways shown above, whilst others add their own adverts (e.g if you use a VPN to access a website, you might see more adverts than you would otherwise). Some services use multiple methods to make money so be very careful of what you do while using a VPN.

So, you’re probably wondering, “why should I use a VPN if there are all of these risks?” Well, the answer is simple. Popular VPNs are used by millions of people so if they were breaching your security, then someone would have reported it (look up info about your VPN). Furthermore, the large number of people using such services means that the average user is relatively insignificant, and is unlikely to be focused upon by both their local government and the provider. VPNs are useful, but just remember to be careful while using them; as long as you know the risks and take measures to avoid them, your information should be secure. In theory, a good VPN should ensure that no one is able to see what you access. For ensuring the highest levels of security, or if you have time and money to waste, consider looking into setting up your own VPN. if not then look into tor (the onion router) but otherwise, most VPNs should be safe for menial tasks.



Turing Completeness

By Michael Lowe (Y13)

You may have heard the term "Turing complete" before. When something is Turing complete, it essentially means that (although it might not always be easy) you can write any computer program/ algorithm with it. How can we define this formally?

For a machine or system to be Turing complete it needs to be able to simulate a Turing machine.

So, that begs the question—what is a Turing machine?

A Turing Machine is "a mathematical model of computation that defines an abstract machine" invented in 1936 by, as the name suggests, Alan Turing. It is essentially the simplest form of a computer that can carry out *any* algorithm. A Turing machine has an infinite tape of 1's and 0's, and a 'head' that can read, write and move one place left or right according to some conditions. These conditions are fed into the Turing machine as binary code. You can think of this code as the algorithm that the computer needs to carry out. The tape acts as the input and output as well as the temporary memory while the program is running.

Such a computer can, in theory, calculate anything a modern personal computer can. There are a few main differences, though:

1. A Turing machine, by definition, must have infinite memory (as in order to be able to process *anything,* it can't be restricted by the length of its tape). On the other hand, no physical computer can solve a problem which involves storing googolplex bits.

2. A Turing machine can take as long as it likes to solve a problem—it is just a mathematical concept—but the computers we have access to need to be able to complete most of their tasks quickly, or else they become useless.

3. Most importantly, modern computers add a lot of extra 'fluff'. A laptop, for example, has a screen, camera, operating system (OS), keyboard, mouse and countless other things which add to the experience of using the computer. When I say that a Turing machine "can do anything", I mean this on the lowest level possible; a Turing machine can *calculate* anything a modern computer can—it just requires its inputs and outputs to be in binary. Because this binary can almost always be converted to and from whatever format you want, most computers are equivalent in terms of what they can compute—and (when we ignore the memory) can simulate a Turing machine.

Since a Turing complete system needs to be able to simulate a Turing machine (which can solve any computational problem, remember), a Turing

complete system must be able to compute anything that a Turing machine can too. This means that saying that a system is "Turing complete" is just a formal way of saying that it can compute anything that it is possible for a computer to do, so it is a general purpose computer.

It is worth noting that you don't need to directly show that a system can simulate a Turing machine to show that it is Turing complete—it's enough to show that it can simulate another Turing complete system.

For a programming language to be Turing complete, it normally has to have two things:

First, it must have some sort of conditional branching (e.g. jump to this line if this is true or carry on if not). For this reason, something like HTML is not Turing complete as there are no conditions being tested. However, most programming languages[1] (such as Python, Javascript, Assembly, C++ and even SQL[2]) are.

Secondly, the language must have the ability to change an arbitrary amount of memory. This means that it should be able to use as much memory as it wants to perform its calculations (because a Turing machine has an infinitely long tape). According to this rule, a physical computer can't technically be Turing complete as infinite memory is impossible in the real world.

However, programming languages can still be Turing complete, as long as there are no restrictions in the *definition* of the language. You can think of this as the difference between the rules you need to know to multiply two numbers together (in theory you could use them to multiply any two numbers together) and actually multiplying two numbers together (in some cases, the numbers are just too big).

It isn't just programming languages that can be Turing complete, though. The cellular-automaton *Game of Life* [3] has been shown to be Turing complete (in fact, you can even simulate *The Game of Life* within *The Game of Life* [4]). You can also build a Turing machine with a circuit just made of NAND gates and both the 2019 puzzle game *Baba is You*[5] and *Minecraft* are Turing complete (which is why it is possible to build computers inside the game).

Oddly enough, the human mind is Turing complete [6]. This makes sense: we can easily follow instructions given to us and store temporary calculations in our own memory (or on a sheet of paper) and we can decide to do different actions based on certain conditions.

But if we are Turing complete, then that doesn't just mean that we can simulate other Turing machines and Turing complete systems, but it could mean that other Turing complete systems can simulate us[7].

This raises questions about the very nature of our existence. If we can be simulated by a computer, then would that computer be able to simulate consciousness? Would that computer *be* conscious?

I have no idea, so I'll leave you there.

Edited by Utkarsh Sinha

Notes

1) Some people argue that a programming language has to be Turing Complete, meaning that markup languages like XML shouldn't be considered programming languages.

2) See this Stack Overflow post: https://stackoverflow.com/questions/900055/is-sql-or-even-tsql-turing-complete

3) A cellular automaton is a grid of virtual cells which can interact with each other according to some very basic rules (e.g. the cell dies if it has more than three neighbours.) The *Game of Life* is probably the most well-known cellular automaton, invented by the famous British mathematician John Conway in 1970.

4) https://youtu.be/xP5-iIeKXE8

5) Here is a simulation of a Turing Machine inside *Baba is You*: https://youtu.be/hsXpLx4soQY and here is a simulation of Conway's *Game of Life*: https://youtu.be/DmtKtKSrag. Technically it is only Turing complete if the grid in the game is of infinite size, but I'll give it the benefit of the doubt because infinity is pretty big.

6) Again, I am ignoring the limits of memory size here because if we made a blueprint of the brain that was exactly the same in its structure but with an infinite number of neurones, then that would be able to simulate a Turing machine.

7) Technically this hasn't been proven, but it seems very likely it is the case. This question of whether all Turing complete systems can simulate each other links to the Church-Turing thesis, which is too much for me to discuss in this article.

DID YOU KNOW…

By 2050, roughly 6.4 billion people will live in a city. Cities are the future for humanity, but the failure to manage higher population density or climate change can result in a threat to resources – water, energy, food – and have a profound impact on human health and well-being, the environment and the economy - International Water Association

Ekranoplan A-90 Orlyonok is an example of a ground-effect vehicle which makes use of the ground effect

Flying - Just About: The Ground Effect

Is this a dead end or does it really have the potential to revolutionise the way we travel long distance?

Aditya Vishwanathan and Ray Wang (Y13)

"Ladies and gentlemen, welcome aboard this morning's flight to New York. The flight time will be 7 hours at an altitude of one hundred feet. We expect to depart at..." Wait. A hundred feet? *That's all?* Flying, at a few dozen or hundred feet? Isn't that closer to *not* flying? Although this technology is in its infancy, it is a phenomenon that occurs every time an aircraft comes in to land and one that could change how we fly. This is the Ground Effect.

Firstly, how do planes fly?

Planes fly when their wings generate enough lift to keep them aloft. Their wings have a shape known as an aerofoil (pictured), and this shape is seen in birds as well. Another fact to know is that air travelling at high speed is at low pressure. Therefore, due to the wing shape, when air meets the wing it can go either above or below. If it goes below the wing it has a smaller distance to travel than air above the wing in the same time, meaning it goes slower and therefore has a higher pressure than the air above the wing. This means the high pressure area "pushes" towards the low pressure area, creating lift.

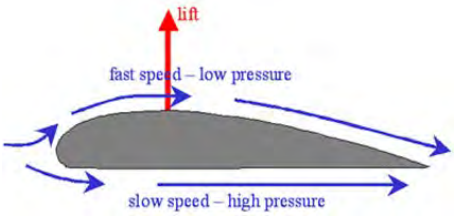


Figure 1 – a simple explanation of how the classic aerofoil shape generates lift

What is the Ground Effect?

The Ground Effect is something that every aircraft experiences when it is close to the ground, when they are taking off or landing. During normal flight, some of the air pushing the plane up will go around the edge of the wing. This creates *wingtip vortices*, which cause an increase in the drag an aircraft will experience. However, at low altitudes, these wingtip vortices cannot be as large as they hit the ground and dissipate, reducing what is known as downwash (less air is directed down). If less air is directed down with less downwash, more air travels horizontally, reducing drag. Furthermore, lift is always at right angles to the resultant wind, meaning that the closer to horizontal the wind is, the more lift is generated

Ground-effect vehicles are generally classed as aircraft that are able to fly very close to the ground by utilising (as the name suggests) the ground effect: a phenomenon where a fixed wing aircraft will generate more lift when it is flying very close to a flat, level surface due to higher pressure air being forced into the space between the lower wing and the ground.

Pros and Cons of WIGs

WIG—Wing in Ground-Effect. There is one glaringly obvious problem with Ground Effect vehicles which is the main reason why they never really took off. Safety. It's quite simple if you think about it. If something were to go wrong with an airliner at cruising altitude e.g. an engine failure, the pilots would have plenty of time and altitude to react to it and would almost always be able to land the aircraft safely. However, when you're cruising at hundreds of miles an hour just

above the surface, you'd have mere seconds to react to problems before a fatal high speed impact. On the other hand, a 2014 NASA study claims that use of GEVs for passenger travel would lead to cheaper flights, increased accessibility and less pollution.

Where has the Ground Effect been used before?

You may be surprised to hear that Ground Effect Vehicles aren't exactly a new idea. The phenomenon was first noticed by pilots as early as the 1920s, but it wasn't until the Cold war that things properly heated up with development of an aircraft purpose built to exploit the Ground Effect. Throughout the 1960s the Soviet Union worked to develop an aircraft capable of flying using the Ground effect and in 1987, the Lun-class Ekranoplan, pictured on the left, came into service. This aircraft flew 4m above the sea and was primarily used to attack ships using guided missiles. It was able to fly at 550km/h and carry 100 tonnes of cargo.

Where are we planning to use the ground effect?

Since the Soviets experimented with their giant flying ships, there have been few modern attempts to utilise the ground effect in vehicles. One example is the Airfish 8, an aircraft that aims to compete in the same market as the conventional speedboat.

It is a far smaller aircraft, only 17x15 metres in size but can carry 6 to 8 passengers over 300 miles. It is said to be quite fuel efficient and only requires car-grade petrol to operate

Another more interesting prototype is in Japan where they have tried to use the ground effect not for boats but instead for trains. Their modular single carriage rides in a smooth trough and uses the Ground effect to lift itself into the ground, drastically reducing drag and friction and allowing for the vehicle to travel much faster. The concept of a levitating carriage is similar to that of Maglev trains. However, this seems to have hit a dead end with other solutions such as hyperloop being developed.

Applying the ground effect to ground based vehicles could have the potential to revolutionise ground travel by lifting vehicles slightly off the surface, drastically reducing the drag/friction they experience and as a result allowing ground effect vehicles to travel at much higher speeds than conventional ground vehicles.

In a world with a rapidly increasing population, the demand for higher speed personal and public travel will only continue to grow.

Edited by Harsh Sinha

Figure 2 – The Lun class Ekranoplan developed and flown by the Soviet Union

How the Race for Efficiency is Fighting Climate Change

By Kishok Sivakumaran (Y13)

In recent years global warming has become a grave concern, not just to the climate-conscious, but to us all. It threatens our way of life with a barrage of heatwaves, floods and hurricanes. Not only do storms and extreme weather brought about by climate change cause damage to people's homes, but they also pose a dire threat to our health. Increased exposure to UV radiation increases everyone's risk of skin cancer and the increase in heatwaves has catalysed the devastating wildfires that have destroyed homes, wildlife and air quality (which provoke existing respiratory conditions). To combat this, engineers and scientists have been innovating their way to a greener tomorrow through enhancements in energy efficiency.

Improvements in generation of electricity

This involves the process of designing more efficient ways of harnessing power from energy sources so that more energy can be extracted from the same mass of fuel. Such improvements are being implemented in the power generation industry and the transport industry. In the generation of electricity in coal-fired power plants, increased efficiency would not only mean more cost-effective energy but reduced CO_2 emissions.

Figure 1 - SSE's "Fiddlers Ferry" coal fired power plant in Cheshire to be closed by the end of March 2020

Alternatively, the phasing out of higher emitting energy sources can increase the innovation of renewable energy as well as significantly reducing greenhouse gas emissions.

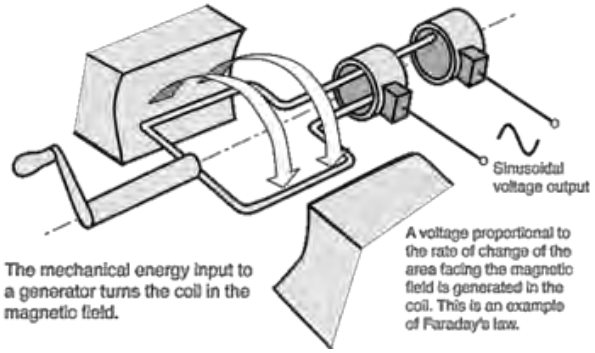


Figure 2 - Diagram demonstrating how regenerative braking works

For the transport industry, the insurgence of more efficient petrol/diesel engines as well as the development of electric cars will most certainly help to fight the climate crisis.

Hybrid technology in cars

Whether it's a plug-in or self-charging hybrid, hybrid cars allow for a car to travel further on the same amount of fuel/ energy. Self-charging hybrids utilise innovative designs that convert kinetic energy that would have been lost to heating the brakes and the surroundings to electrical energy. This is done using an AC generator that uses the rotation from the wheels to rotate a coil in between permanent magnets, which produces electrical energy that is stored in a battery to be used at slow speeds to save fuel and reduce emissions.

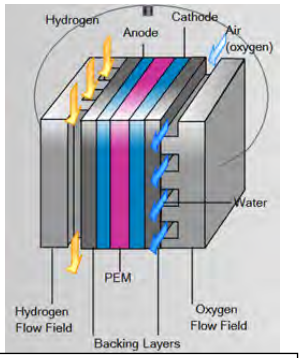


Figure 3 - Diagram of hydrogen fuel cell

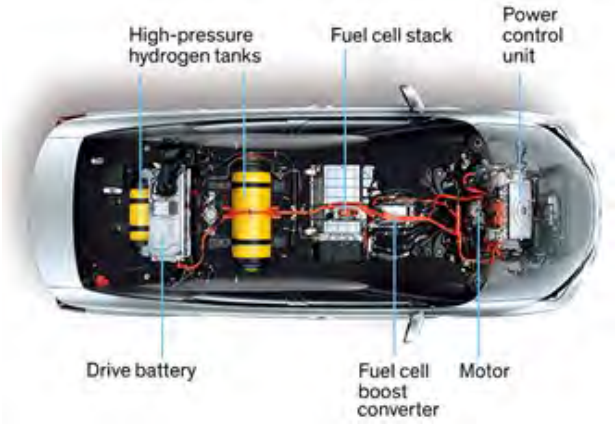


Figure 4 - Drivetrain of the famous hydrogen powered car - Toyota Mirai

Electric Cars

Electric cars are also paving the way to a more efficient future. While combustion engines are improving in efficiency, it is difficult for them to be as effective as power stations anytime soon. As a result, electric cars prove to be more efficient as well as less polluting that conventional combustion engines, allowing for us to continue benefiting from the ability of long-distance travel with cars without having such an impact on the environment. In addition, with the UK transitioning to more renewable energy sources, the emissions from driving electric cars are decreasing year after year. However, there is the current disadvantage that recharging takes a significant amount of time and may slow a journey down.

Hydrogen fuel cells

Is this the fuel of the future? Hydrogen fuel cells use a reaction between hydrogen collected and stored in the vehicle with oxygen in the air to produce electricity to propel the car forward. The most revolutionary part is that water is the only by-product, reducing emissions and reducing the greenhouse effect.

How do they work?

The hydrogen fuel is passed across a platinum catalyst which is used to split up the H_2 molecules to form two H^+ ions and two electrons per molecule:

$$H_2 \rightarrow 2H_2 + 2e^-$$

The electrons pass along the anode to a battery to store the electricity produced (which can also be used to power the motor). Meanwhile, the H^+ ions pass through the proton exchange membrane (PEM). This is a membrane between the anode and the cathode that only allows protons (H^+ ions) to pass through it to the cathode, meaning that all electrons pass along the anode to the cathode via the circuit, maximising power produced per mole of hydrogen gas and thus efficiency.
After the H^+ ions pass along the PEM and reach the cathode, they combine with the electrons from the cathode to form H_2.. Adjacent to this O_2 is taken in by the car from air and the H_2 is reacted with this oxygen to form water.

$$O_2 + 4H^+ + 4e \rightarrow 2H2O$$

Overall Equation:

$$2H_2 + O_2 \rightarrow 2H_2O$$

This is expelled from the exhaust and is the only emissions from the car, reducing greenhouse gas emissions massively whilst also reducing the release of pollutants such as oxides of nitrogen, sulfur dioxide and carbon monoxide, which all reduce air quality and contribute to smog (mostly in urban areas). Additionally, hydrogen fuel cells (provided that there will be many refuelling stations) can provide a clean fuel that can be used for long journeys as it can be refuelled much faster than an electric car can be charged.

The technological revolution is well under way, with emissions to decrease rapidly over the next few decades. If our scientists and engineers continue to innovate, perhaps we may be able to reverse our effect on the climate. Without a doubt, a green future is in sight.

Edited by Ray Wang

Silicon and Molecular Transistors

By Syed Shah (Y12)

Transistors are a fundamental component in many electrical circuits, including in the processors of modern computers, where they act as switches and are used in combination with each other to form logic gates. The smaller the transistors are, the more you can fit onto a chip, making your computer faster. But as engineers work to make transistors increasingly small, they begin to approach the physical limits of their miniaturisation (see Figure 2).

However, in 2009, the first working molecular transistor was made. Whereas a normal silicon transistor found in a computer will be 50 or so atoms long, a molecular transistor is controlled by the energy state of a single molecule.

But don't get excited yet! Although this advance in transistor miniaturisation could theoretically allow for a huge increase in transistor density on computer chips, with today's engineering technologies it would be impractical to use them in any useful way.

How a 'normal' silicon transistor works

A transistor is like a switch: its purpose is to prevent electrons flowing from its 'source' to its 'drain', unless a positive voltage is applied by its 'gate'.

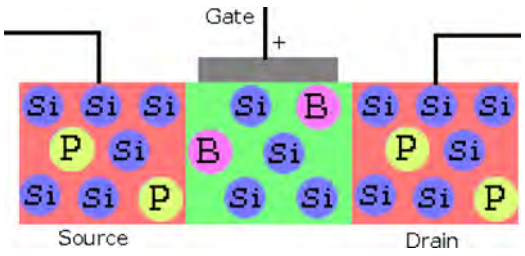


Figure 1: An example silicon transistor

Silicon (Si) atoms have 4 outer electrons, so form (8 - 4 =) 4 covalent bonds

We can 'dope' silicon with boron (B) or phosphorus (P) impurities. Phosphorus has 5 outer electrons, while boron has 3.

Because of this doping, the 'source' in Figure 1 has extra electrons (from the phosphorus atoms), while the green section in the middle has 'holes' where electrons could be (due to the boron atoms). The electrons try to fill these holes by moving from the phosphorus atoms to the boron atoms.

This creates a 'depletion layer' between the middle section and the source. It is an area of negative charge, which repels further electrons coming from the source.

When the gate supplies a positive voltage, the electrons in the depletion layer are attracted to it. This removes the negative charge in the middle of the transistor, i.e. the depletion layer, and allows electrons to flow from the source to the drain.

Molecular transistors

A team from the University of Yale, USA, and the Gwangju Institute of Science and Technology, South Korea, made the transistor by attaching one benzene molecule (which has delocalised electrons) to two gold electrical contacts.

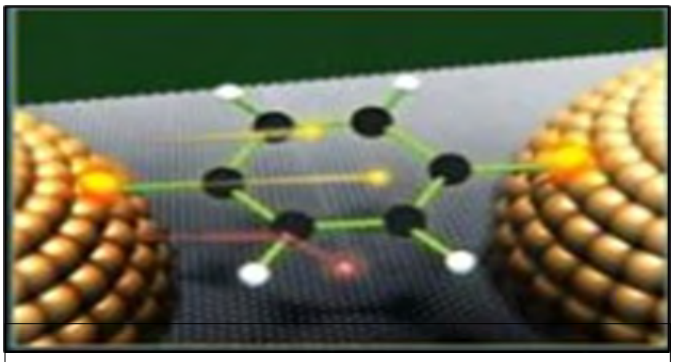
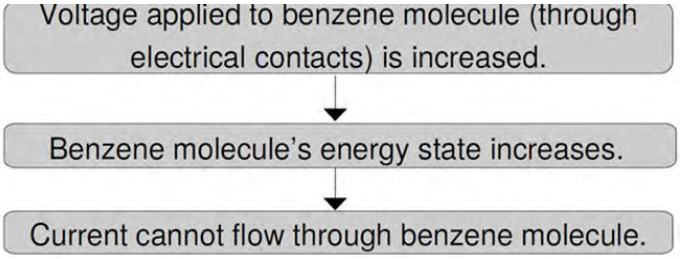


Figure 3[4]: Reconstruction of a benzene molecule attached to two gold contacts, with electrons flowing across from one gold contact to the other, through the benzene molecule.



The researchers were able to make the molecule control whether current could pass through it. They did this by changing the voltage they applied to the molecule (through the contacts), which would in turn change the molecule's energy state.

The future?

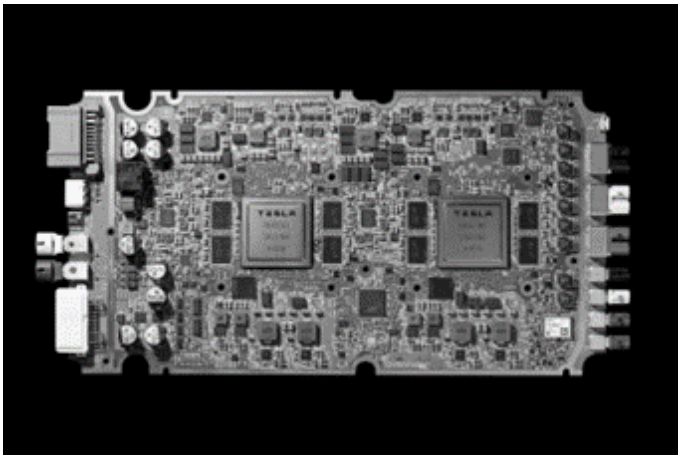
No. At least, not yet. This particular molecular transistor was not reliable enough for use in everyday electrical circuits. In fact, the first reliable one was made in 2015, and even that transistor had some "unexpected behaviour"[6]. It is also quite difficult for companies to position individual molecules on their chips!

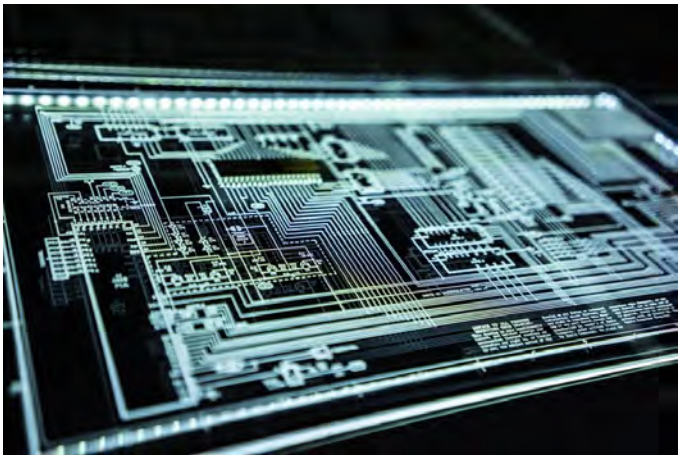
Edited by Neos Tang

Why Tesla and AI Will Save the Environment

By Neel Patel (Y12)

In April 2019, Elon Musk promised that Tesla would soon have a million-mile battery, an unprecedented value (twice the current line span of contemporary Tesla vehicles). Through more and more innovation, Tesla is closer than ever to revolutionising the electric vehicle industry. Fundamental to their success, is their use of computer systems and artificial intelligence (AI).





The Importance of Artificial Intelligence

Tesla's previous development of AI was driven by a partnership with hardware manufacturer Nvidia. Nvidia have stated that they have not programmed any "explicit object detection, mapping, path planning or control components into the car" and "instead, the car learns on its own to create all necessary internal representations to steer, simply by observing human drivers". This self-learning aspect really highlights the endless possibilities for this technology and, indeed, electric cars. But, if you thought that was exciting, Tesla have developed their own, in-house chip, which is, astonishingly, 21 times faster than this old Nvidia model, for only 80% of the cost.

Each car's computer has two AI chips and makes use of a redundant design for better safety. Both chips have two accelerators that are specially designed to run neural networks, the AI components that Tesla's cars use to understand the road and be aware of their

surroundings. Each chip performs up to 72 trillion operations each second, and the system is built to handle the analysis of 2100 frames of video each second. Both chips have their own power lines, a backup in case the first chip fails. Each chip makes its own judgement of what the car should do next. The computer compares the two assessments, and if the chips agree, the car takes action. Another key reason why the implementation of AI is extremely important to Tesla vehicles is because of its significance in repairing problems, such as the overheating of components, through software patches. This helps to maximise the user's experience, encouraging them to stick with Tesla and, perhaps more importantly, electric cars. These are far less harmful to the environment, and thus it is beneficial if electric cars are used comparatively more than their petrol and diesel counterparts.

The Million Mile Battery

The average lifespan of a car is about 150 000 miles. The average driver drives about 13 500 miles every year, equating to about 11 years as the lifetime of an average car. This means that, remarkably, a 1 million-mile battery would last about 74 years – more than the average driver will drive their vehicle. This could mean that electric cars will last much longer than their petrol counterparts. Much more notably however, electric vehicle batteries can be repurposed after being exhausted by the car: they can be used in power management to support a grid and therefore reduce electricity consumption, as well as make storage cheaper and more efficient, until they are finally disposed of.

The obvious benefit of this is that the batteries limit manufacturing waste and electricity consumption, two very prominent problems in this age. Furthermore, this exceptional technology means that these Tesla cars will not require constant operational maintenance, enabling them to appeal to a whole new type of consumer, and since they are less harmful to the environment, this is better for the planet, as a whole. However, critics have constantly mentioned the difficulty in producing such a battery. The battery is integral to Elon Musk's plans for 'robotaxis' and other electric vehicle applications. At this current moment, Tesla have already secured a patent for 'Dioxazolones And Nitrile Sulfites As Electrolyte Additives For Lithium Ion Batteries'. The cathode crystal structure and chemical composition of the new battery makes it far more resistant to any damage.

The Future of Tesla

As stated on their company mission statement, Tesla wants to 'accelerate the world's transition to sustainable energy' and believes that the world needs to soon stop relying on fossil fuels and move towards a zero-carbon emission source. So, we can expect to see the company focus on this goal on the future, and we will see it influence their future technological decisions. One thing is for sure: electric cars, as well as artificial intelligence for this purpose, will make many more appearances in the future.

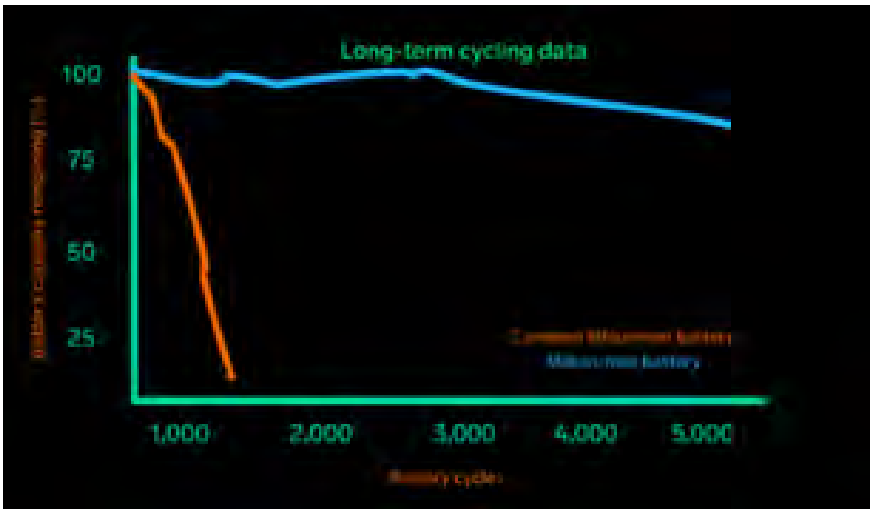


Figure 2: Graph showing how the 'million-mile' battery would retain 95% of its life

Are Electrofuels the Answer for Clean Aviation?

By Navaneeth Kanakkaparambil (Y13)

In today's world, we take the gift of flying for granted. It connects us to almost every part of the world and has become so ingrained to our lives. Air travel is one of the most common methods of transport and is becoming increasingly accessible every day. In 2018 alone, 4.4 billion people travelled through the skies and this number is only going to get bigger. However, the use of such an incredible feat of engineering does come with its costs.

Like most methods of human transport, aviation has negative environmental impacts. Approximately 35% of CO2 emissions from the transport sector were contributed by the aviation industry and that is just the tip of the iceberg. There were many other impacts of nitrogen oxide and particle emissions. These emissions only seem to be increasing. According to many researchers, the aviation industry is projected to take up almost a quarter of the world's carbon budget in 2050. Electrofuels are seen to be the solution to many who envision a future of emission-free aviation.

Electrofuels are a class of carbon-neutral fuels. They are electricity-based and are produced by obtaining electrical energy from renewable energy sources and then storing this energy within the bonds of liquid or gaseous fuels. Some potential electrofuels of the future are n-octane, methanol, methane, hydrogen and ammonia. Producing basic electrofuels involves combining hydrogen and carbon dioxide and many of the production methods are exciting and innovative; with some methods involving the excretion of electrofuels by genetically modified microorganisms. If the electrofuels are to be carbon neutral and sustainable, the hydrogen has to be obtained through the electrolysis of water and the carbon dioxide has to be captured straight from the atmosphere. It is also imperative that the electricity used is from renewable and non-carbon-related sources (i.e. hydroelectricity or solar power). Other methods involve the use of drop-in fuels and the mixing of ammonia with more reactive fuels. Drop-in fuels are synthetic and

Figure 1 - Different types of available fuels at a gas station

completely interchangeable substitute for the conventional petroleum-derived hydrocarbons. It does not require any modifications to the engine, fuel system or the fuel distribution network. This reduces costs from modifications and allows electrofuels to be easily implemented.

The use of carbon-neutral electrofuels has numerous advantages. The most important one being a significant reduction in aviation's carbon footprint. Moreover, some potential electrofuels with no carbon content will also have no nitrogen oxide emissions or soot particle emissions. In addition to this, electrofuels have a higher energy storage capacity compared to electric batteries. Therefore, these fuels can provide significant breakthroughs in future developments of electricity based planes and combat of climate change. Furthermore, aircraft manufacturers would only need to make slight modifications to their engines and fuel pump designs for the aircraft to use electrofuels as they are a type of drop-in fuel . This significantly reduces the costs of developing new aircraft designs to accommodate the use of electrofuels.

However, the production of electrofuels does not come cheap. It has a very capital intensive production process and this is also one of the main reasons why many organisations are reluctant to research and develop electrofuels. The costs also mean that it may not be commercially viable unless there were subsidies or government policies that encourage the production of these fuels. The manufacturing process also has a huge thirst for electricity and energy. According to estimates, the use of electrofuels comes with such a huge demand for electricity that delivering at least 50% of projected demand would consume 24% of the electricity generated in the EU today.

While the use of electrofuels can completely mitigate all carbon dioxide emissions from air travel, other more harmful, and damaging pollutants such as nitrogen dioxides and particulate matter cannot be reduced significantly if electrofuels are used. Furthermore, producing a working electrofuel that is relatively cheap, not energy-consuming and emission-free would be very difficult with current world technologies and resources. However, a breakthrough in the production of electrofuels would be the beginning of a new age in not only aviation but also within the transport industry. It would open a new chapter in aircraft design and avionic innovation. The combat against climate change and meeting world carbon targets would suddenly become more achievable. What's more? We would still be able to enjoy the gift of flying. Electrofuels are a very promising solution in achieving reduced emissions, and they may be a huge stepping stone to emission-free flying if there are advancements in current technology and research. So, electrofuels may be one of the answers to clean aviation but it has the potential to be the answer to clean aviation.

Edited by Ray Wang

DID YOU KNOW…

Images of nebulae do not often display how they actually appear – alongside visible light, nebulae emit other types of light, unobservable to human eyes, such as infrared and ultraviolet light. These are substituted for other rich colours, completing the brilliant images which we see.

Hubble Telescope: NGC 4833 Globular Cluster

Modelling Galaxies

How can we accurately create models of galaxies?

Leo Kavanagh (Y11)

In places still untouched by the sprawl of humanity, away from the glare of the cities, if you look up at night, you will see the sky split in half by a river of light - a band of stars stretching from horizon to horizon. This famous sight is just one of the vast arms of the Milky Way, the huge spiral galaxy which is home to the Earth, and its star, the sun. The vast majority of all stars are contained within these enormous structures, whose origin and formation are key to understanding the universe as it is today.

Before the invention of modern telescopes, it was thought that stars were spread evenly throughout the cosmos (although the French astronomer Charles Messier did observe galaxies without realising what they really were), and it was only in the 1920s that eminent astronomer Edwin Hubble discovered that the Andromeda galaxy was separate to the Milky Way, leading to the realisation that there were many such galaxies, spread across the universe.

Ever since Hubble's discovery, modelling the behaviour and formation of galaxies has been an area of scientific interest, especially since it can provide insights into the early universe. One method of doing this, that has been made practical by recent advances in computing technology, is called N body simulation - simulating each individual star and its gravitational pull, leading to a highly accurate picture of galactic formation - which shows how elliptical galaxies form[1], for example. These models often display highly unpredictable and chaotic behaviour, as a small difference in the gravitational pull of just one star can have a huge impact on overall behaviour.

Furthermore, this method is very computationally inefficient, especially with large numbers of stars - for every single new star being simulated, its gravitational effect has to be taken into account on every single other star. To help reduce the computational power needed, algorithms such as the Barnes-Hut algorithm[2] can be used. This algorithm takes the space that the stars are in, and divides it up into quarters again and again until every square contains one star (see image). Then, if 2 squares are far apart enough, they are treated as whole objects, with their mass being the sum of the masses of the stars that they contain, hence avoiding working out the gravitational pull of each individual star.

However, this isn't the only approach to modelling galaxies, as it fails to take into the account of factors such as gas clouds and nebulae; many physicists favour mathematical models of galactic development based off observation[3], which describe how certain values, such as the height, width, and luminosity of galactic disks change. Simulating galaxies has also provided insight into the behaviour of dark matter: in many models it is standard to include a “dark matter halo”[3], modelling the dark matter that is proposed to exist around all galaxies - the success of simulations that incorporate this feature bolsters the evidence for the existence of dark matter, as well as helping scientists to understand just how it influences the behaviour of galaxies.

The equations that make up these models have a lot in

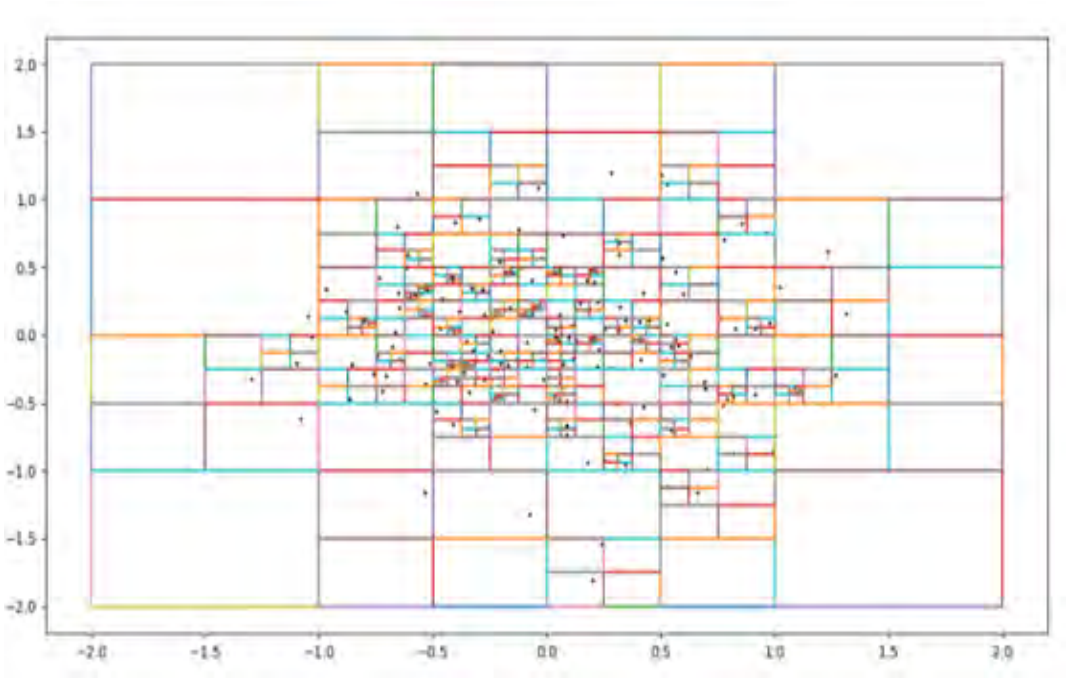


Figure 1: the Barnes -Hut Algorithm

common with those used to model the behaviour of fluids. For example, the behaviour of a flattened disc can be modeled using something called a Poisson equation, which is a type of differential equation (an equation that describes how a function changes). This type of equation is a significant part of the Navier-Stokes equations for describing fluids, which I wrote about in my last article. The significance of this is that it shows that galaxies are so large that they don't behave as lots of small particles, but rather as one huge, changing object - rather like how a liquid, made up of lots of small particles, behaves in a fluid way as a single entity. This elegant concept allows us to model galaxies as continuous distributions.

Recently, a more unorthodox method of modelling galaxies came to light, using the new techniques of machine learning[4]. The researchers trained a CNN (Convolutional Neural Network) - a tool that is normally used for image recognition for its ability to learn to recognize features - to try to predict the results of an N body simulation. After training on 10,000 such simulations, the neural network was able to accurately predict the outcomes of a number of scenarios, astonishing many academics. The success of this powerful new tool could signal a new era in our centuries-old quest to find our place in the universe.

Edited by Neos Tang

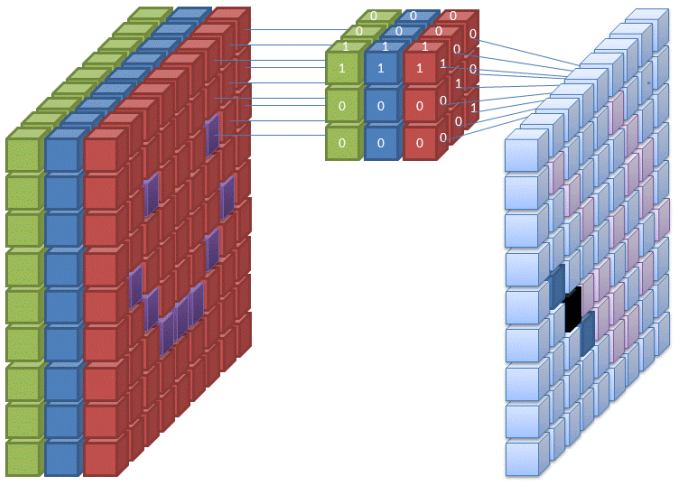
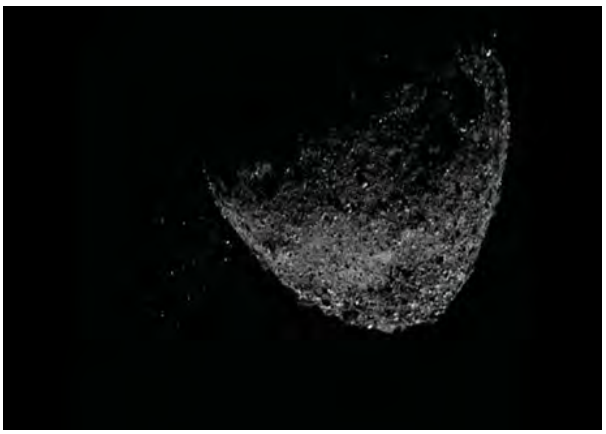


Figure 2: How a CNN aggregates data

Who Wants To Be A Trillionaire?

By Ansh Sharma (Y13)



Referred to as the stepping stones to the solar system, asteroids have been travelling above us for billions of years but have just started to be seen as somewhat accessible to humanity. These enormous entities are potentially vital injections into the mining industry as resources here on Earth continue to deplete; for example, the Asteroid Bennu has an estimated worth of $669 million - but pales in comparison to Ryugu ($82 billion) and even more so to Davida, which is valued at $100 trillion due to the abundance of metals. While they can provide precious metals such as iron, gold and platinum, perhaps the most important substance we can acquire is one we are all familiar with: water. With potential to extract and use water directly from asteroids instead of having to take it with us, a whole new frontier of space exploration may be at humanity's fingertips.

What are asteroids?

Asteroids are the remnants of the debris that was present during the birth of our solar system but was unable to form into planets. After dust condensed and aggregated into denser and larger structures, these structures continued to merge and became planets. However, some were unable to do this, and these are the asteroids we see today. This is further seen as some larger asteroids are called planetoids while some are big enough to be considered dwarf planets – such as Ceres. The vast majority of asteroids in our solar system are present between Jupiter and Mars – these are referred to as Jupitar Trojans; due to the planet's gravity, they co-orbit both Jupiter and the Sun around the barycentre of the two celestial bodies.

There are three main classes of asteroids:

C- type

Carbonaceous asteroids make up the largest sector at approximately 75% of all asteroids. Due to their high percentage of Carbon and other minerals, they are known to have a relatively low albedo (how much light is reflected without being absorbed). Many are found in the outer ring of the asteroid belt.

S-type

These stony (siliceous) asteroids form around about the mark of 17% of all asteroids, thus making them the second most common after C-types. Due to their composition of mainly iron and magnesium silicates, they have a relatively high albedo and are found on the inner side of the asteroid belt predominantly, becoming more scarce the farther out you look.

M-type

Metallic asteroids are usually, but not always, made from nickel, iron and some trace amounts of stone. They are also thought to be a potential source of iron meteorites.

Why do we mine them?

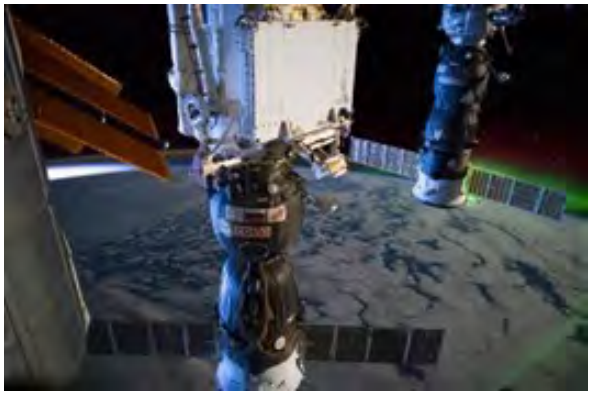
With the average cost of luggage in space running up to around $54,500 per kilogram, people have long considered it to be more cost effective to find resources in space once we get there; this is known as 'In-situ resource utilisation'. By saving costs on launch, space exploration can become far more frequent and achievable within the ever-tightening budget constraints of the world's governments

For example, mining water and extracting could be essential for humanity to become an interplanetary species, as it can be split into its component parts of Hydrogen and Oxygen to serve as fuel on top of being used to sustain life and grow plants. This would remove some of the boundaries we currently have in terms of space

travel as we can sustain ourselves as we delve deeper into space.

This may also allow fuelling stations to be set up in space, increasing our ability to venture farther away from home using these galactic pit-stops

However, it isn't all as easy as that. For example, while on the moon our machines and equipment are grounded by gravity, this isn't as easy on asteroids due to their smaller mass. Altogether, asteroids in the belt only amount to 4% of the mass of the moon alone. Furthermore, bringing them back poses its own problems. If we do bring back the spoils from asteroids such as 16 Psyche which is 95% metals and valued at a staggering $700 quintillion (one quintillion has eighteen 0s), we would immediately push the supply to a level that demand could never match. This would immediately reduce the value of the metals to near enough nothing. This would therefore make the whole exercise of bringing the asteroid down completely redundant.



Potential Ways to do it?

While not yet perfected, many private and state funded companies have begun to design drills and mining machines already. For example, one concept is PVEX – a heated coring drill. This will go under the surface, heat up a column of material such as ice in order to vaporise it then cool it down again for the water. This is only one of the possible designs that have been tested and are being developed today.

Edited by Harsh Sinha

The Quantum Problem: Which Cherished Principle of Physics Do We Get Rid Of?

By Kiran Lee (Y13)

We all tend to believe that most (if not all) things happen for a reason. Indeed, intuitively this seems obvious, perhaps even to the point of indubitability - we look for causes of events all the time, and trying to imagine something happening for no reason at all causes us to almost intellectually recoil. Being the pattern-seeking animals that we are, constantly deducing and inferring explanations for phenomena we encounter, it's hardly surprising that many of us (whether knowingly or not) subscribe to some form of what is known in philosophical circles as the Principle of Sufficient Reason, or PSR. Simply put, this principle posits that 'for every fact *F*, there must be a sufficient reason why *F* is the case.' Whether the principle holds even in theory has been debated among philosophers for centuries, but a challenge to its validity may well have arisen from the weird world of quantum mechanics. Some of the most popular hypotheses in current quantum mechanics seem to violate this principle, asserting that some events are simply uncaused - although of course there are other explanations that deny this. To investigate why quantum mechanics could overturn our intuitive ideas of the necessity and pervasiveness of causation itself - and why it could also not pose a challenge to them - let us take a dive into quantum physics, and maybe leave a bit more sceptical of causation than when we jumped in

Most people have some idea of how quantum mechanics defies our common intuitions about the way the world works. Schrödinger's Cat is probably the most famous example of a quantum phenomenon, and has been well-known to the general public for a while now. For those unaware, Schrödinger's Cat is a thought experiment that is (or rather has become) a way of explaining both some of the fundamental principles of quantum theory and how strange the theory can be at times. Imagine a cat in a sealed box, with a vial of some gaseous poison that will go off at a random time, killing the cat.

Without looking in the box and observing whether the cat is actually alive or dead, the cat's state living or not is undetermined - in fact, it is almost as if the cat is alive and dead

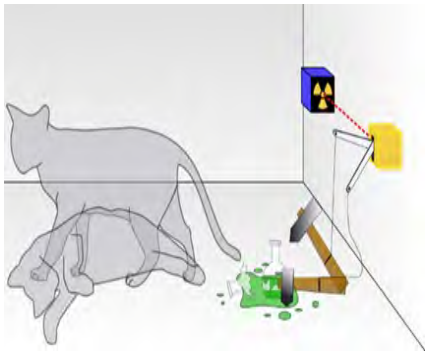
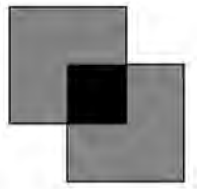


Figure 1 – The cat is in an indeterminate state until it is observed. In some sense it is alive and dead at the same time!

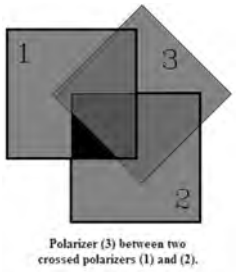
at the same time until it is observed by some measurement device (in this case us opening the box). In a similar way, while quantum mechanics offers probabilistic accounts of where a particle may be detected (just as how we can possibly say that after a certain time the cat has some percentage chance of being alive, if we know the possible times that could cause the poison to be released), the particle's position is undefined until it is observed. However, when hearing of this example, one common idea people come away from it with is that there is still some cause of the state being one way or another - in this case our timer and poison - and that all we are missing is the ability to observe that state. While their belief might not be wrong, it's certainly not one that is without its challengers - indeed in order to accept it we might have to abandon some of our most valued principles in physics. The alternative to this is that there is no underlying hidden variable and that the physical world is at least partially non-deterministic, with some effects not having underlying causes in the properties of particles, and why this might be considered counterintuitive is left to the reader to deduce

A quantum experiment that you can do at home involves three polarising filters (polarised sunglasses for example), and helps us explain the potential problems with the idea that a hidden - but determined - variable, akin to mass or charge, is causally controlling the behaviour of particles, and that we merely lack the capability to know of this variable (usually known as 'hidden variable theory'). All you need to do is take two filters that are aligned (all the light passing through the first also passes through the second) and rotate one 45°. The amount of light getting through the filter will, of course, decrease (half the light gets through the second filter, but our eyes do not judge brightness



Crossed axes.

linearly with intensity so it might not look like only half). However, add a third filter between the first two at 22.5° to each and more light seems to get through all three filters than just the original two! This time, 85% of the light passes through each filter after the first, resulting in over 70% of the

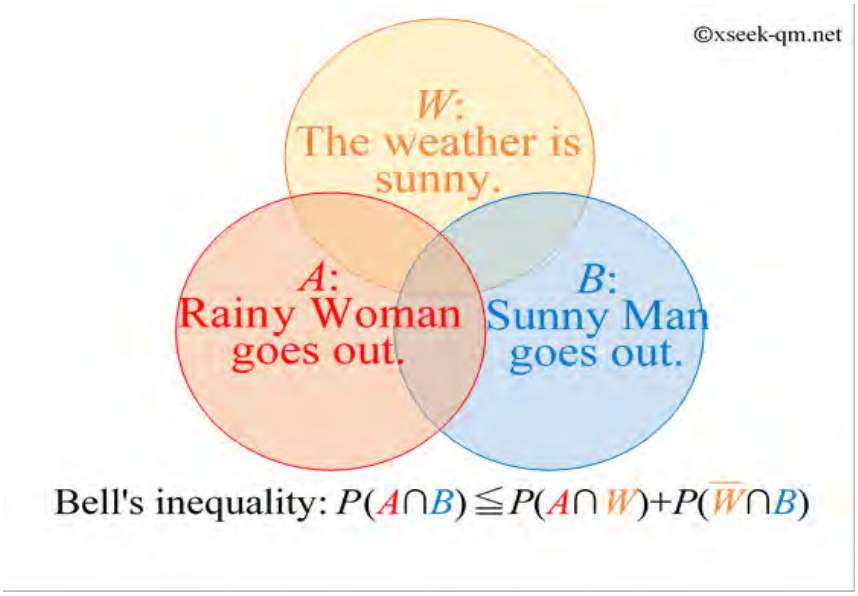


Polarizer (3) between two crossed polarizers (1) and (2).

light passing through both (as opposed to 50%). This presents a problem for hidden variable theories because it seems to imply that they are mathematically impossible.

Light is made up of many, many tiny 'packets' known as photons, and each one has a certain chance of passing through each filter. If the

photons had some hidden variable dictate that they had a 50% chance of passing through the second filter after passing through the first, then why did adding a third filter between the two change the proportion that passed through the third? These results are known as a Bell Inequality, and they pose a serious problem for hidden variable theories. There seem to bet wo ways we could go about solving this problem, the first being that there is no hidden variable that is a sufficient cause



of each photon's behaviour, and that its properties are fundamentally indeterminate until it is observed, like the cat in the thought experiment. This is the violation of the PSR that we hinted at earlier - no underlying property of the particle causes the observations that we see. The second possible explanation is that reaching the intermediate (22.5°) filter changed the hidden variables affecting each photon, and that the properties it possesses before going through the filter are different to the properties afterwards in some meaningful way, which causes the discrepancy between the two tests.

However, we (or at least scientists with large research grants and high-tech labs) can reformulate the experiment to use two photons that are entangled - which here we can say for simplicity means that they have the same chance of being blocked when they arrive at the same filter - instead of one photon at different times. Despite the fact that there is seemingly no possibility of these photons changing their property between filters two and three (since each photon goes through its respective filters at the same time, leaving no time for the photons to affect each other and change each other's properties), the same effect is observed. This would seem to eliminate the possibility of hidden variable theory, but there are ways that it can survive - these ways just also come at a huge cost

Faced with the results of these experiments, we must ask how we can explain them. One possible solution, that favoured by the Copenhagen interpretation of quantum mechanics, does away with the idea of realism - which in the context of physics means that there really are particles out there with defined properties independent of our measurements of them. The Copenhagen interpretation is what we posited earlier, where there are no underlying determined properties of the particles that act as sufficient causes for what we measure them to be. However, there are other possible explanations for what could be occurring. Remember when we said that there was no way the particles could influence each other since they're too far away? Well there are some hypotheses that, rather than to do away with realism, and deny the principle of locality in physics (the idea that events can only be triggered by causes immediately adjacent to them in space, and that information cannot travel faster than the speed of light). This group of theories includes ideas the de Broglie-Bohm interpretation. Finally, it may be possible to preserve local realism even with these experiments through radically reinterpreting how we think the theory applies to reality. Hypotheses of this nature include Everett's Many Worlds interpretation (often called the 'multiverse' theory, where every possible quantum event happens in some world - for example, the cat is alive in some worlds and dead in others), and superdeterminism, where a chain of determined events from the Big Bang itself determined where the photons would go, allowing their strange behaviour to have non-local causes due to them not actually being tested independently. Unfortunately, each of these theories comes with their own problems: the modal implications and metaphysical commitments involved in positing a huge (possibly infinite) multiverse need no explanation, and superdeterminism is completely untestable so we would never be able to experimentally confirm or disprove it.

Unfortunately, we are currently unable to produce the experimental conditions that would let us distinguish between the various quantum interpretations (and in the case of superdeterminism, we never will be) so until a point is reached where we can decide, we will have to weigh up the interpretations on their intuitive plausibility alone. Would we rather give up realism, locality, be committed to the multiverse or espouse a completely untestable hypothesis? The choice is ours to make.

Edited by David Kuc

Space Travel to Mars

By Neos Tang (Y13)

With Earth becoming increasingly more populated, and its population becoming increasingly more curious, the idea of visiting Mars for all manner of purposes is becoming increasingly more interesting and likely. In the previous issue, the potential colonisation of Mars was considered alongside the potential advantages and drawbacks, but how will we actually get there?

Method I - Opposition-class Mission:

An opposition-class mission is so named because it refers to the positions of Earth and Mars when the rocket is launched. “Opposition” is what occurs when Mars is at its closest to our planet, and is when the mission begins. In the first stage, the rocket blasts off from Earth, flying on a relatively straightforward and simple (or rather, curved and simple) path to Mars, which lasts approximately 200 days. After only a short stay of about a month on Mars, the return journey begins - the astronauts set off again, headed back home. This very short stay is required to ensure the alignment of Mars, Venus and the Earth, such that the shuttle can easily enter Venus’ orbit. This “Venus swing-by” serves as a “gravity assist”, essentially using the planet’s orbit as a slingshot for the shuttle, changing its trajectory and velocity and sending it back to Earth (requiring less propellant to be carried on the spacecraft, while also decreasing re-entry speeds into Earth’s atmosphere). This return journey would take another 250 days to complete, leading to an approximately 500 day round trip.

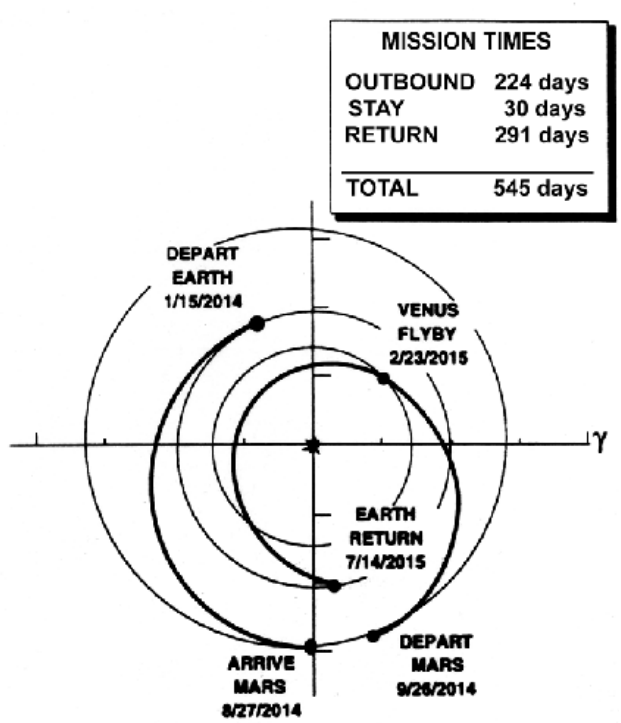


Figure 1 - an opposition-class mission, with a Venus swing-by

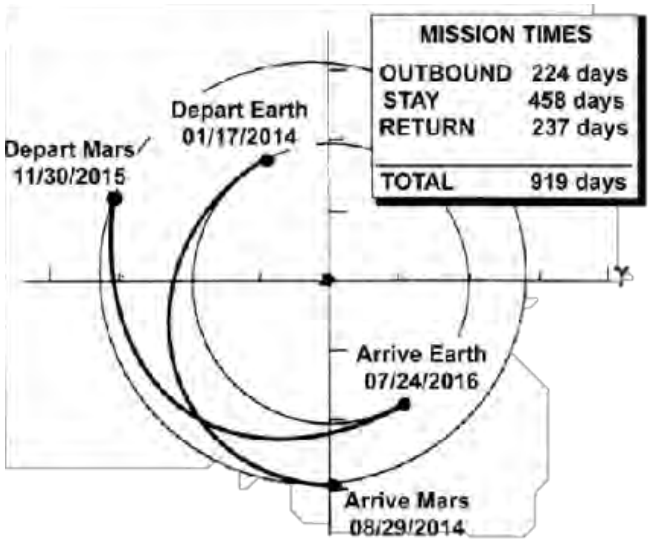


Figure 2 - a conjunction class mission

Method II - Conjunction-class Mission:

This mission instead occurs when Mars is furthest from the Earth at launch, which is known as “conjunction”. This route simply entails flying to Mars, and then (after a far longer stay, compared to opposition-class, of about 500 days) flying back home again. The transit time is again about 200-250 days each way. Each of the trips in this mission has low energy requirements, due to the alignments of Earth and Mars leading to low energy trajectories. This mission offers an approximately 900 day round trip.

Method III - A Combination of I & II:

This method allows astronauts to stay on the surface of Mars for a long time, while having relatively short transit times. The outbound journey towards Mars takes only about 150 days, while the return journey takes only 100 days. Approximately 600 days are allowed on Mars' surface, too, while waiting for Earth and Mars to realign to facilitate a shorter trajectory which enables a far shorter transit period. Although this journey is greatly reduced in length, it is very important to note that this trajectory requires far more energy.

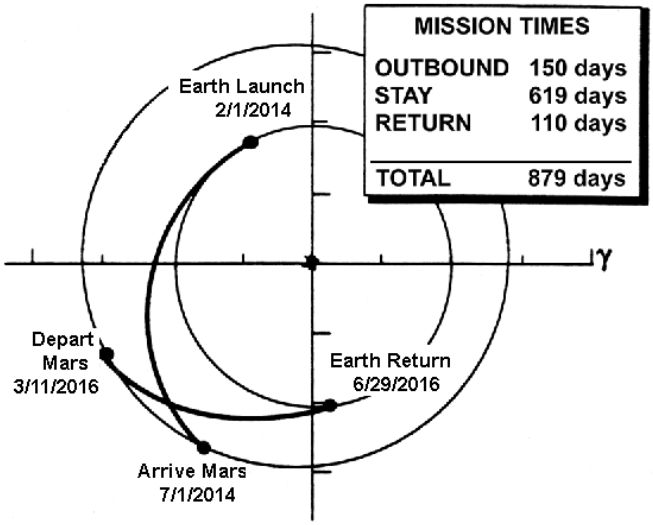


Figure 3 - a combination of I & II

The Crocco Fly-by:

Also known as the "Crocco Grand Tour", this mission is slightly different to the others mentioned here, in that it does not entail a Mars landing whatsoever. It is, however, extremely fast and energy efficient, requiring only half the energy and a third of the time - the whole mission begins and ends within approximately one year. Devised by Gaetana Crocco in 1956, it involves using the rockets on the spacecraft only while leaving the Earth. The craft flies to Mars, passing very nearby and, using the planet's orbit as a gravity assist, is slingshotted towards Venus. The spacecraft again travels very close to Venus which, in turn, slingshots the craft again - this time back home toward Earth.

Which to use?

The main issue with Methods I and II for manned missions is the extremely lengthy transit time. Although Method I also has a far shorter overall mission length, the surface-stay time on Mars is restricted as a result, and so would likely not be the best option for a manned mission. Extended periods of time in a zero-gravity environment (i.e. during the space-travel) is also unhealthy for humans. Although the Crocco Fly-by and Method I both include Venus swing-bys, which would allow for relatively close observation of Venus, it is worth noting that being within the orbit of Venus will also increase the crew's exposure to cosmic rays - high energy solar particles, which are very dangerous for humans. Therefore, increased shielding on the spacecraft would also be required. With rapidly improving technologies, and great strides in spacecraft manufacturing, it seems that Method III is the best option for manned missions to Mars as of now. Regardless of the greater energy requirements, and so greater cost for each mission, the short transit times ensure that the astronauts stay in zero-gravity for far less time. These extra costs will also eventually decrease, while journey times decrease even more. The benefits for the crew, both physically and mentally, are brilliant.

Edited by Utkarsh Sinha

The Dizzying World of Spin

By Nanda Girish (Y13)

If you ask your physics teacher why a moving current generates a magnetic field they will reply with spin. If you then ask your physics teacher what spin is you will receive one of two responses; a reminder of the constraints of curriculum-based education - "I appreciate your enthusiasm, but that is a little advanced at this stage," or an explanation that is too complex for your mind to understand. This is partly because spin is a topic that is not understood very well at the moment, and partly because it is hard to explain spin without delving into undergraduate level particle physics. This article aims to explain spin as simply as possible, whilst also referring to key scientific concepts that are considered above and beyond.

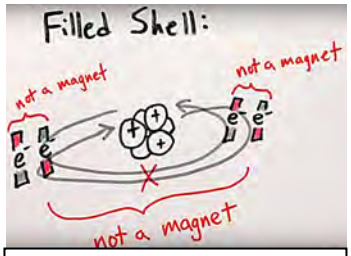


Figure 1 - electron configuration of atoms with full shells[1]

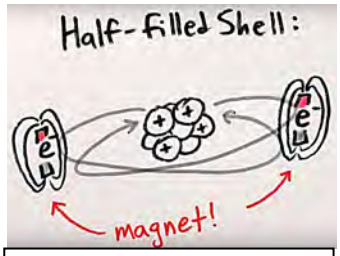
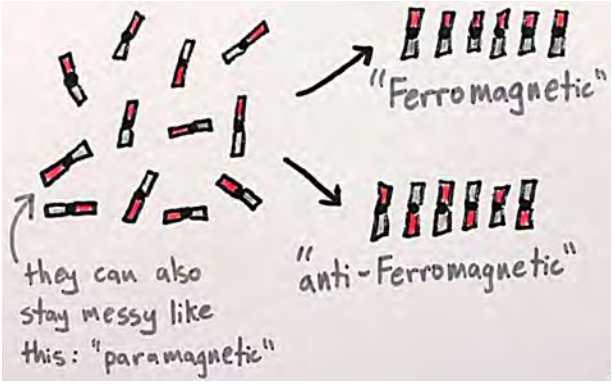
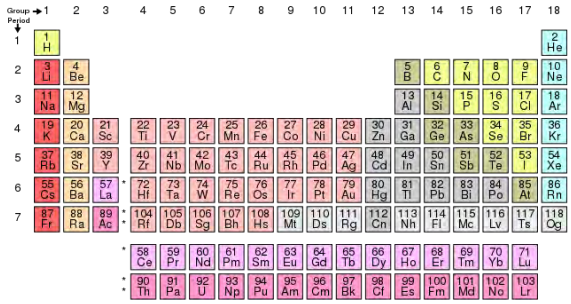


Figure 2 - electron configuration of atoms with half-filled shells[2]



What is spin?

Spin is a fundamental property of subatomic particles (electrons and quarks - which are the building blocks of protons and neutrons) that causes the particle to behave like a magnet (which explains why a moving current generates its own magnetic field)[1]. We cannot simplify the definition of spin any further because it is a fundamental property, just like charge



and mass - we can't make those simpler. If all elements have orbiting electrons why aren't all elements magnetic? This question can be answered in two levels: atomic, and crystal[2]. In the atomic level elements with full outer shells have electrons that orbit the nucleus in opposite directions as well as electron pairs that arrange themselves with opposite spins - which cancel out[2]. In contrast, elements with half-filled shells contain unpaired electrons, and the spins all point in the same direction.

This explains why elements towards the extremities of the periodic table aren't magnetic whereas elements towards the centre of the periodic table are magnetic. Next, the half-filled atoms can arrange themselves in a way that either cancels out their spin or promotes their spin or in a disordered fashion (whichever requires the least energy) = which brings us to the level of crystals.

This explains why some central elements are magnetic such as iron, whereas other central elements aren't magnetic such as chromium (which is anti-ferromagnetic) as iron arranges its atoms in a way that amplifies the magnetic moment, whereas chromium arranges itself in a way that cancels out its magnetic moment[2].

Note: spin does NOT refer to spinning of fundamental particles - this is a misconception that arose due to the fact that early scientists thought the magnetic field was brought about by charged particles spinning on their own axis (however we now know this to be false).

Spin has many applications both real and hypothetical such as MRI scanners and quantum computers, which both depend on quantum superposition (which states that a particle can exist with two spins at the same time). Next time: quantum computers: their impacts and applications.

Edited by Harsh Sinha

Quantum Entanglement: Why Is Faster Than Light Communication Still Impossible?

By Max Ma (Y12)

Mankind has always needed to send information. First it was letters, then pigeons, after which telegraphs and telephones were invented. More recently, radio waves have begun transmitting messages at the speed of light. However, the distance over which messages need to be sent is constantly increasing, and the inability of messages to travel past the speed of light has emerged as a significant hurdle that has prevented the official exploration of space. A message from a spacecraft near Pluto (at the edge of the Solar System) would take five and a half hours to reach Earth. The continual transmission of messages back and forth would therefore be very time consuming, greatly lowering the efficiency of communication.

If we could send messages instantaneously, there would no longer be a communication time problem -messages would be sent and delivered immediately. However, this was implicitly noted to be impossible by Einstein in his theories of relativity, since nothing can travel past the speed of light.

But then, the study of quantum mechanics began to take off, and the principle of quantum entanglement was first described by Erwin Schrödinger in 1935 (see **The Quantum Problem**). The experiments of Freedman and Clauser in 1972 and those of Alain Aspect in 1982 showed that the results of quantum entanglement experiments were, in fact, in accordance with the theory.

How does Quantum Entanglement work?

Generally, the particles entangled are photons which are created when a violet laser beam is fired through a special type of crystal (beta barium borate – BBO). This emits two photons that come out in opposite directions. The polarisations of these photons are opposite to each other due to the conservation of angular momentum. The two photons are then separated, but still entangled, meaning that measuring one of them will instantly reveal the state of the other.

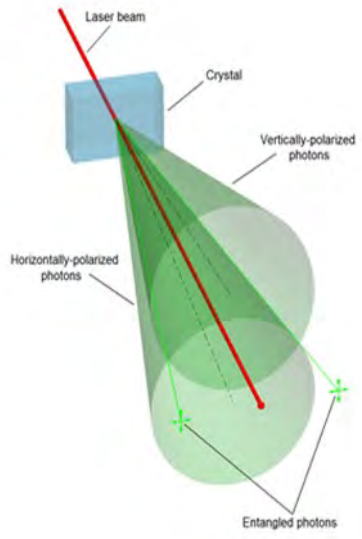


Figure 1 - photon entanglement

A pair of these entangled particles are given to two people - let's call them Chris and Bob. This means that when one of them is measured on one side by Chris, he will know the state of Bob's particle. The remarkable thing is that this property stays true regardless of the distance between Chris and Bob, and hence it would seem that if a message is encoded in Chris's particles, then the message could be instantly sent and delivered to Bob because of this property

Why can't messages be encoded?

Based on this theory, it would seem that the simple solution is to let Chris make his particles hold values of +1 or -1, and then interpret these positive and negative values as binary code (1s and 0s), allowing Bob to decode the binary message back to the original message. There can be many particles on both sides - some on Earth, and some on a spaceship on the edge of the solar system, for example - enabling messages to be sent to and from one another instantly.

Unfortunately, this is impossible. Quantum entanglement only persists while the original state remains unchanged, meaning that if Chris tries to force his particle into a certain state (done using a Raman transition), changing -1 to +1, then Chris' particle would be +1, but so would Bob's, because his hasn't been changed. This effectively means that any change to one of the entangled pair would break the entanglement, hence meaning that the state of Chris' particle is not relevant to that of Bob.

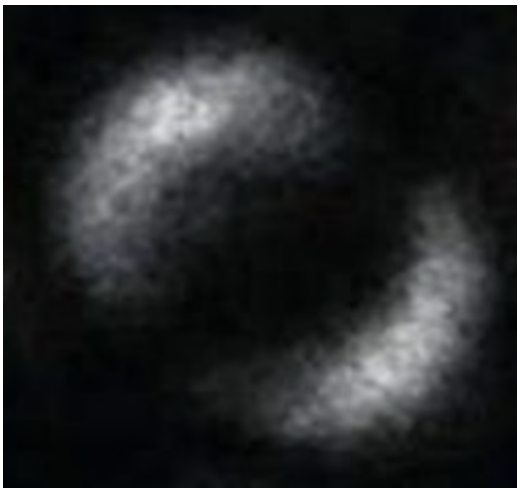


Figure 2 - Physicists' first image of quantum entanglement in photons - 2019

The chance of correctly sending one of either 0 or 1 would be 50%, the same as if there hadn't been any entanglement in the first place. Therefore, messages clearly cannot be sent through the encoding of the particles themselves.

A different method?

Perhaps Chris could send information by measuring one particle after 2 seconds, then 1 second, then 2 seconds again, etcetera, where 1 is a 1 in binary and 2 is 0 in binary, allowing the timing of the measurement to be used instead to communicate, meaning that the randomness of the actual particles is not relevant. However, this is also flawed. This is because Chris' act of measuring the particle on Earth does not tell Bob that a particle has been measured, so no information is transmitted in this way

Another possible method involves measuring the probability distribution of the particles that Chris sends, where if it is 100%, a 1 is signified, and if it was 50%, a 0 is signified. However, the subtle flaw here is that quantum states cannot be copied between particles without already knowing what state they are in, and so they would no longer be entangled if the quantum state was copied in producing the probability distribution in the first place.

For these reasons, although quantum entanglement is an extremely powerful tool that could be used in other areas such as encryption, it unfortunately remains impossible to communicate faster than the speed of light.

Edited by Neos Tang

Non-Newtonian Fluids

By William Lu (Y12)

States of matter may seem to belong to key stage three science due to their simplicity. However, there are certain fluids that defy the conventions of liquids and have very mysterious properties

The Theory behind Non Newtonian Fluids

Firstly, a Newtonian fluid is a fluid, which abides Newton's Law of viscosity, so that at a constant temperature and pressure the fluid maintains a constant viscosity. Hence, a Non-Newtonian fluid can change its viscosity even at a constant temperature and fluid.

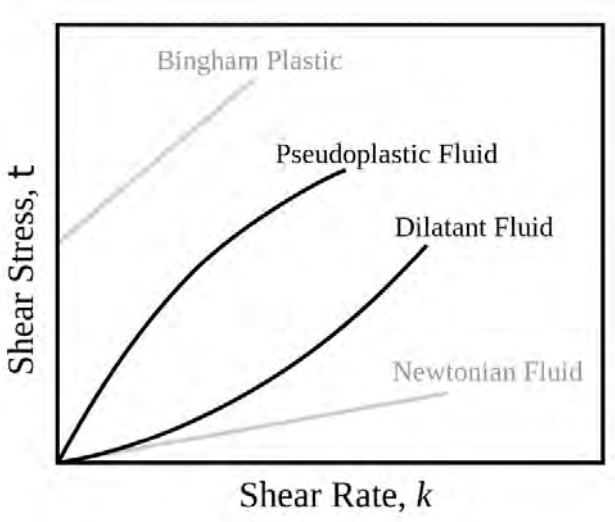


Figure 1: A graph depicting the viscosity of Non-Newtonian Fluids

There are several types of Non-Newtonian fluid, which all have variable viscosity resulting from having work done on the fluid (sometimes known as 'shear'). Shear stress is the stress between layers of fluid that acts parallel to the surface of fluid and shear rate is the rate at which the force is applied during flow. The viscosity of a fluid depends on its shear stress divided by its shear rate.

Types of Non-Newtonian Fluids

A Bingham plastic is a fluid, which first requires an initial input of shear stress before it starts to act as a Newtonian fluid. An example of such would be mayonnaise, since once you squeeze it out of its bottle or packet it starts to flow out of it like a Newtonian fluid with a constant viscosity.

When stress is applied to a shear thinning liquid, however, its viscosity decreases and it becomes runnier. Examples include ketchup, blood and paints. This property is especially useful for industrial processes as they act like gels which can help reduce friction through lowering their viscosity under stress. They are also known as pseudoplastic fluids. Similarly, there are also thixotropic fluids which also become less viscous when stress is applied, but their changes in viscosity are more gradual.

The opposite of a shear thinning fluid is a shear thickening or dilatant fluid (no surprises there). They increase in viscosity when stress is applied and the most common example of a shear thickening fluid or even Non-Newtonian fluid is a substance known as Oobleck, which consists of cornflour and water. When stress is applied to it such as vibrations from a loudspeaker the liquid goo suddenly solidifies as its particles lock together causing it to group together like a solid.

As it is a shear-thickening fluid, Oobleck becomes runny as soon as the applied pressure is removed, so if one were to run across Oobleck they would have to continuously be in motion - they would otherwise sink into it as it would no longer be viscous enough to support them.

A rheopectic fluid is the opposite of a thixotropic fluid where it increases in viscosity when stress is applied over time.

In theory, shear thickening fluids can also be used for body armour as, when runny, they are fluid and agile and when viscous, they become hard, so they can provide protection against blows.

Edited by David Kuc

Quantum Superposition

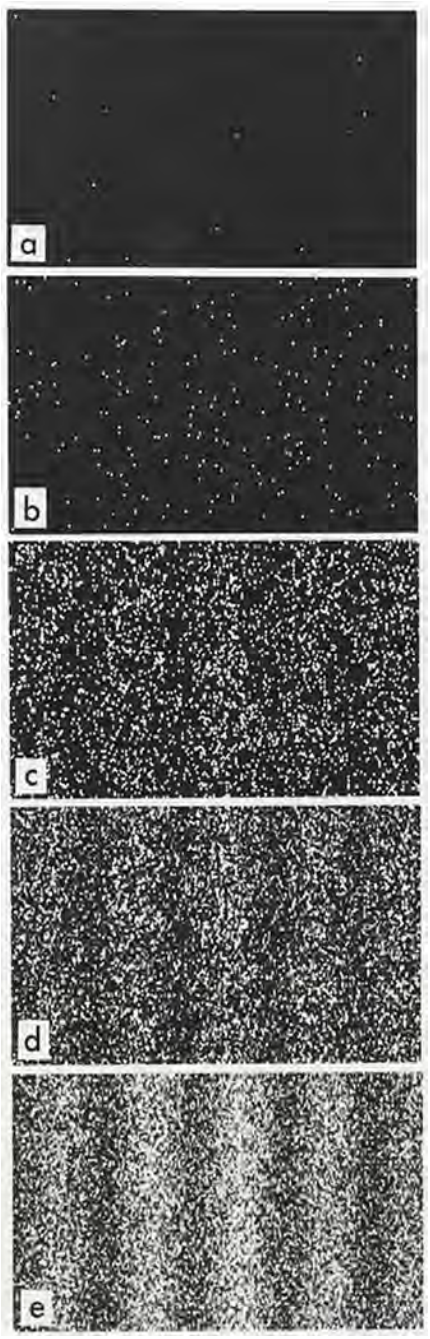
By Boyu Xiang (Y12)

I am sure many of you have heard of quantum superposition at some point, perhaps as a strange, illegible addendum to a physics article on the Internet which you mistakenly clicked on and decided to peruse. It was likely forgotten within the same day, that esoteric titbit of knowledge swept away in the tidal wave of the monotony of everyday life. Perhaps your mind would have retained a few key words—maybe reading this introduction has brought flashes of “Heisenberg” or “interference” to your mind. These key words are in fact very relevant, and pertain very much to the topic of this article.

Those who read my previous article may have a decent understanding of this topic already, as particle-wave duality is very closely related to quantum superposition. For the majority who have not, I will briefly summarise it here: every object can be thought of as both a wave and a particle, behaving as a wave or a particle depending on the situation - the less massive an object, the more wavelike its behaviour. A planet for example, (almost) never behaves like a wave, while a photon, with very little mass, rarely behaves like a particle. A demonstration of this predominantly wave-like behaviour is Thomas Young’s famous double slit experiment, in which evidence for interference of light was found (explained in more detail in my previous article), which seemed to be conclusive proof at the time that light was a wave.

As interesting as that apparent proof was, a more modern rendition of the experiment yielded results more relevant to the topic of this article - superposition. Instead of using a constant beam of light, scientists fired off electrons, one at a time. Electrons are widely regarded as particles, but also fall under the particle-wave theory, behaving as if they were a wave in the experiment. One would think that sending a single electron at a time would result in particle behaviour - after all, there is nothing for it to interfere with. However, after releasing the electrons, one after another, an interference pattern built up. Initially, it was thought that one electron could somehow pass through both slits simultaneously, and then interfere with itself before recombining. To test this theory, detectors were added to determine which slit the electrons had entered. Strangely, with the detectors, an electron was only found to have passed through one slit, and now the interference pattern no longer appeared, as if the simple act of detecting them caused them behave like a particle. [(1)]

It was as if the electrons were interfering with something that simply wasn’t there, and that, owing to observation, that “something” disappears. As peculiar as that sounds, the official scientific answer for the phenomenon is essentially the same: the electrons were



interfering with themselves, and our attempts to discover why this occurs causes this self-interference to disappear - a conclusion that gave rise to the theory of quantum superposition. According to quantum superposition, a particle can be in many different places at once, and have many different characteristics at one time. Until it is measured, the particle can be in many

positions, and these positions of the electrons can interfere with each other as if they were completely separate. This means that every possible position that the electron can be in corresponds to a wave pattern, rather than a particle one. (2)

Quantum superposition can even be applied to everyday life, not merely to seemingly ludicrous experiments. It is possible that plants are already using this principle to space out chlorophyll, which enables energy to be transferred much more efficiently during photosynthesis than classical physics allows (3). The double slit experiment has also been successfully replicated with buckminsterfullerene, C60 (4), a molecule which is much larger than an electron or photon.

And so, there is indeed a chance that superposition could be applied in technology as we become able to utilise larger and larger particle.

Perhaps the most famous theoretical application of quantum superposition is Schrödinger's cat. In this thought experiment, a cat is trapped with deadly poison, and the decay of a particle releases this poison - killing the cat. If you do not observe the cat or the particle, the particle exists in the both states of having decayed and having remained stable simultaneously. This means that, at that same time, the cat is both dead and alive. Ironically, Schrödinger intended this thought experiment to be a critique of the Copenhagen interpretation (that a system of particles is in superposition until it interacts with the outside world), highlighting its absurdity. However, just the opposite occurred - many agreed that the cat would indeed be both alive and dead. It seems that showing the absurdity in an already rather absurd topic does not discredit it. (5)

Now, a summary, to bring this discussion of a convoluted theme to a close. Quantum superposition is the theory that within a system, particles can display practically opposite characteristics at once, such as being in many different positions. The most common interpretation is that that this "superposition" collapses once it is observed externally. If you, like I, are particularly intrigues by this strange occurrence, I would encourage you to research it further - the links in the references should be an interesting starting point.

Edited by Neos Tang

Polish: The Matt, the Dark and the Shiny

By Divy Dayal (Y12)

In order to comprehend how we can make things shinier we have got to understand what it is. Shine is a reflection, and thus a mirror is one of the shiniest objects. But if we zoom in on a molecular level, what is reflection now, since previously it was light bouncing off? What does it mean to "bounce off?"

A common theory within scientists is the *particle theory*[1] which states that all substance is formed of atoms of some form. As EM waves come into contact with a particle, they are absorbed and give energy to outer electrons in the particle, making them move to a higher shell. As the electron falls back into its normal shell, it releases the energy (in the form of an EM wave) back the way it came. Reflection, if slowed down and zoomed in upon, is the absorption and emission of EM waves. The shiniest possible surface must therefore be that which emits identical waves to those that it initially encounters.

Looking at the opposite side of the scale, a new material has been developed where 99.965% incoming light is absorbed: "Vantablack". It is so effective that it is nearly impossible for human eyes to detect any deformity in the material, as can be seen in Figure 1.

The question some pose is why particles in highly reflective materials all emit EM waves in a parallel direction. Particle physicists agree that emission is random and spontaneous and thus explaining this phenomenon is beyond current understanding. However, it is a similar question to why we should assume all incident rays are parallel in the first place.

In order for there to be maximum reflection, the substance should be as smooth as possible, usually achieved through abrasion.

Vantablack absorbs 99.965% of incident light—so much that our eyes cannot define the edges and shape of this sculpture.

Emery paper, toothpaste, polish and scrubbers can all be used to reduce surface grit and inconsistencies.

This is immensely useful in modern engineering and fashion, from sparkly dresses to shiny cars, and shiny teeth to mirrors in an analogue ammeter to prevent parallax error.

Moreover, total internal reflection is used in fibre optic internet cables and endoscopes, saving and improving the lives of the general population. And for a select few, Vantablack is the perfect colour for their clothing. All in all, reflective substances are a quest for many, perhaps particularly evident in the military penchant for shiny parade shoes.

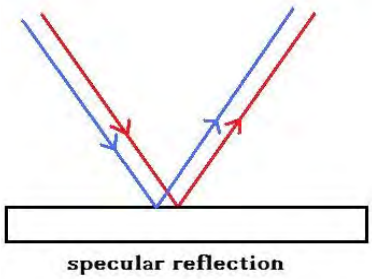
A pair of exquisite parade shoes is one of the ultimate wishes of anyone involved in the military. Gleaming on all sides, blazing their shine, providing a distorted face on the toe cap as you look down after endless hours of scrubbing and desperate attempts to improve

their condition. The top method for using polish to get a good shine is to:

- Scrub any present dust off the toe cap.
- Distribute the polish evenly throughout.
- Allow it to dry.
- Brush vigorously.
- Take a small cotton bud, dampen and circle the toe cap.
- Rinse gently in steaming water.
- Allow to dry.
- Repeat.

Why is this the best method? Viewed from a physicist's eyes, these steps have scientific credit. Ensuring the shoe is clean ensures a smoother surface, which is essential for their to be parallel reflecting rays (which, as identified, results in maximum reflection). Polish as a substance is a lubricant, and therefore smooths the surface of the leather to allow for *specular reflection*[2].

Steaming water is the newest method, since it melts the polish to such an extent that it further lubricates but also does not coat the existing shine. Repeating this process is best since it creates layers of polish, so that if any light is not reflected by the top layer, it is reflected by the lower levels. The more layers there are, the higher the percentage of reflection.



specular reflection

Specular reflection is when reflected rays are all in a parallel direction.

Using chemicals and other abrasives, a higher quality shine (mathematically can be measured by how similar the properties of the incident and reflective rays are) can be achieved, and once again reinforces the unlikely source of the sparkle, glamour and glitz - sooty, diligently applied, unattractive polish.

Edited by Utkarsh Sinha

Key Terms

Particle model: A theory devised by scientist to explain the structure of materials, assuming that substances are made from small varying subunits which are elemental throughout the universe.

Specular reflection: When incident rays are absorbed and remitted such that reflected rays are all parallel to one another, often resulting in a clearer image.

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Images:
1. Asteroid Bennu shown discharging particles into space
2. ISS. Satellites such as this could be benefactors of in-space refuelling

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