SCIENCE JOURNAL 2022

SENIOR PHASE

Editors' Note

Dear Readers,

Even amidst the struggles of the pandemic during the past few months, our writers and editors have persevered to continue putting together our fascinating collection of articles. The amount of time and effort our writers have spent in creating and perfecting their submissions to the best of their ability has been incredible to witness, reflecting their dedication and passion for science poured into the pages of this journal.

Our article selection this year touches upon many aspects of science, including natural sciences such as biology, chemistry, physics, and human sciences like psychology, giving writers the opportunity to explore their topics of interest and further their learning beyond the classroom. So, whether you are a science enthusiast or just a casual reader, this journal will certainly teach you something new.

In addition, we would like to appreciate the work of our designers on the journal covers. They are based on the designs of the Nobel Prizes, demonstrating the potential that our students have shown to be future influential figures at the forefront of scientific discovery, research and innovation. The Junior & Middle Phase cover is inspired by the Nobel Prize in Physiology or Medicine (2021), awarded jointly to David Julius and Ardem Patapoutian

"for their discoveries of receptors for temperature and touch." On the other hand, the Senior Phase cover is inspired by the Nobel Prize in Physics (2021), awarded "for groundbreaking contributions to our understanding of complex systems", with onehalf jointly to Syukuro Manabe and Klaus Hasselmann and the other half to Giorgio Parisi.

The covers of the Junior and Senior Phase journals can also be viewed together as one cohesive image: a depiction of humans interacting with nature. This not only shows how the scientific disciplines as a whole are greater than the sum of its parts, but also represents the collaborative work conducted by our writers to collate such an enriching journal. We feel elated to see the immense curiosity embodied by our sheer number of passionate writers, all interested in exploring the world around them.

With this year's Science Journal being the biggest, boldest, and most ambitious of its kind so far, we feel proud and honoured to finally present it for viewers to read. Therefore, we would like to thank you, the reader, for showing interest in this publication. We hope that it will inspire you to stay curious, pursue the sciences, and maybe even write an article yourself for the journal next year!

Happy Reading!

The Science Journal Editorial Team 2022

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Also a great thank you to Mr Bayne!

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Does Music Really Help You Concentrate?

Man Yan Tse 11F

Nowadays, music has become a quintessential part of our lives. Many listen to it while completing other tasks - be it finishing assignments, studying, or even driving with the reason being that music helps them concentrate, But something doesn't seem quite right here. How would having another thing to pay attention to help you concentrate better? In fact, wouldn't it do the exact opposite by distracting you? The more you think about it, the less it makes sense.

SO, HOW DOES IT IMPROVE CONCENTRATION?

Our brain has two attention systems - conscious and unconscious. The conscious system is the one that helps us focus on the task at hand while the unconscious system is the one that is always scanning our peripheral senses for stimuli. The unconscious system doesn't shut down while you are working, which can be extremely distracting, especially if the task at hand is extremely dull or tedious.

However, music that you like can distract the unconscious system, preventing it from constantly picking up on stimuli in the surroundings, which in turn helps you concentrate on your work. This is because music is one kind of "non-invasive noise". ("Does music really help you concentrate?", 2022)

In a study conducted in 2016 where 200 students participated, 96% of them agreed that music helped them concentrate better. (Muslimah & Apriani, 2020) Of those who had a habit of listening to music while completing their tasks, they were unable to do as well on a test without any music than those with music.

ARE THERE ANY BENEFITS THAT MUSIC BRINGS, OF WHICH INDIRECTLY IMPROVES CONCENTRATION?

In fact, music actually brings a lot of benefits. For example, it can increase motivation, improve your mood, and also help you memorise and interpret information better.

Gold et al. (2019) found that music elicits responses in reward-engaged areas of the brain. This shows that music can act as a reward, which can motivate people to concentrate more on their work, and also improve their mood.

In another study conducted in 2017, it is suggested that certain music can improve our mood (Lehmann & Seufert, 2017). With a good mood, you are more likely to be able to learn or study with more efficiency. Furthermore, music can help you relax and reduce stress, which can also lead to better performance.

In a study done by Stanford University School of Medicine (Sridharan et al., 2007), music, namely classical music, has been shown to benefit your brain in acquiring and understanding new information. In addition, a 2014 study found that some forms of music can improve people's memory, thus allowing them to perform better on memory and processing tasks.

WHAT OTHER SOUNDS, OTHER THAN MUSIC, CAN HELP YOU CONCENTRATE?

Some people find that the lack of sound could actually make an unnerving atmosphere that makes it hard to work in. Other ambient noises such as white noise, nature sounds such as ocean waves, rain, or birdsong, and binaural beats have been shown to help.

In a study conducted in 2017, it was found that white noise can significantly enhance the learning capacity and memory of participants. (Angwin et al., 2022) It also muffles background noise, which can also help you focus.

WHAT TYPE OF MUSIC HELPS YOU CONCENTRATE?

Studies have shown that classical music is very helpful when you are trying to get your tasks finished. Just like how instrumental music is encouraged if you need to finish your work, lyrical music is very much discouraged. This is because the brain automatically picks up on human speech and vocalisation, which can distract us, therefore doing more harm than good.

Video games soundtracks are also very popular choices for improving concentration. Actually, they are designed for such purposes. The music is not supposed to distract the player, but rather stimulate their senses and blend into the background, and tune out the unconscious system.

WHAT CHARACTERISTICS OF THE MUSIC HELPS YOU CONCENTRATE?

The most important thing - of course - is that you enjoy the music. The music you like can improve your performance, while music you don't impede it.

As the music is supposed to stay in the background, it should not be too loud. Music that is too loud would end up drowning out your thoughts, rather than just distracting your unconscious system. The music should not be bleak either, as it would sap your enthusiasm for the task. The music should not be too predictable - like a metronome, as that would bore you out, but it cannot be too chaotic either - like atonal music, as they are constantly changing while your brain is trying to expect what would happen next, which ends up distracting you from your task.

CONCLUSION

As can be seen, listening to music as you work can help in various ways such as increasing your motivation, improving your mood, and strengthening your ability to memorise and take in information, particularly instrumental music that you enjoy. Other than that, ambient sounds could work as background noise for people who easily get distracted by music.

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EPIGENETICS

Ginny Park 11W

Epigenetics is the study of how the DNA in cells interacts with smaller molecules to activate or deactivate genes due to the presence or concentration of molecules. This is simply how the DNA in our body is read and how our environment and behaviours can affect who we are.

HOW DOES IT WORK?

To start from the basics, Deoxyribonucleic acid (DNA) is the molecule in cells that contain the genetic information responsible for helping organisms develop and function. It is the body code that works similarly to how alphabet letters are rearranged to form words and sentences and decides the colour of our eyes, our height, and many other behaviours (Genetics Home Reference, 2021a). The first step of the process is transcription when the DNA in genes is copied to produce messenger RNA code. This then gets translated when the messenger RNA (mRNA) travel to the ribosome, where transfer (tRNA) carry amino acids to the ribosome from the protein. DNA is transcripted, translated, then proteins are made for cells to function ("What is gene expression?", 2021).

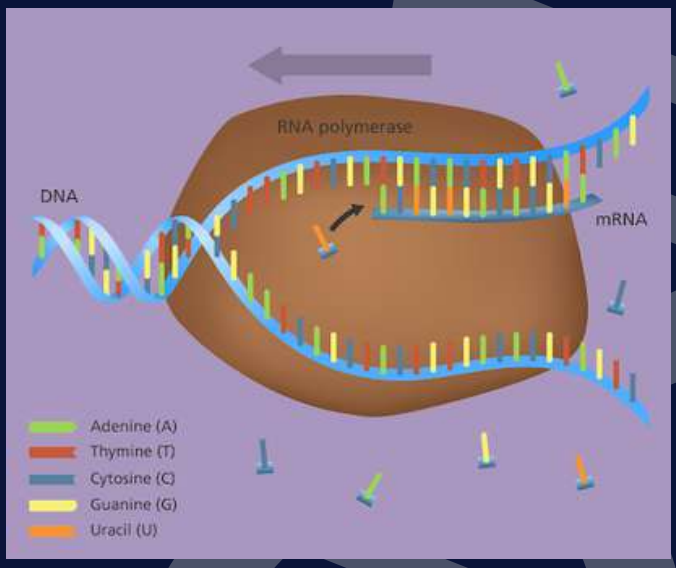

Fig 1: *A diagram of genome transcription.*

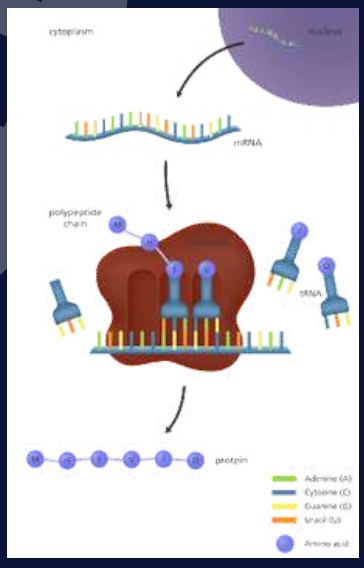

Fig 2: *A diagram of genome translation.*

Epigenetics start to factor into this process by either boosting or interfering with the transcription part of the process via epigenomes. These are chemical tags attached to the DNA or to proteins that either make DNA inaccessible and decrease the production of a protein or more accessible and increase the production of a protein (Ennis, 2014; Guerrero-Bosagna, 2016).

HOW DO EPIGENETICS CHANGES AFFECT OUR GENES?

There are three ways epigenetic changes can take place, either through DNA methylation, histone modification, or non-coding RNA. Firstly, DNA methylation is a mechanism where methane groups made out of 3 hydrogen and 1 carbon atoms are added to specific parts of the DNA, inhibiting transcription and blocking the proteins needed to read the gene. If there is more methylation, the gene is more repressed and tends not to show up and vice versa. This can be reversed through demethylation. ("What is Epigenetics?", 2020; Genetics Home Reference, 2021b).

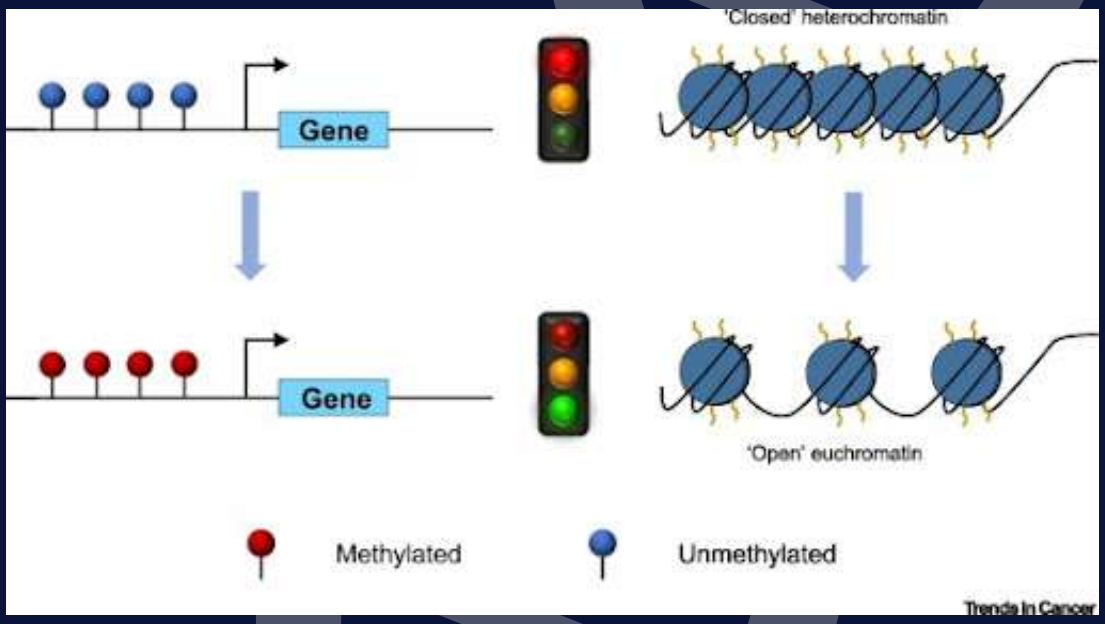

Fig 3: *A diagram of DNA methylation*

The second method involves the DNA around histone proteins. These special histone proteins help shape chromosomes and control gene activity. If you imagine the histones as a ball and the DNA as a rope around it, wrapping the ball too tightly turns off genes and makes them inaccessible, while wrapping it loosely histone makes the genes accessible. Histone modification is adding chemical groups to the histones in order to change how tight the rope is wrapped around the ball. ("What is Epigenetics?", 2020; Genetics Home Reference, 2021b).

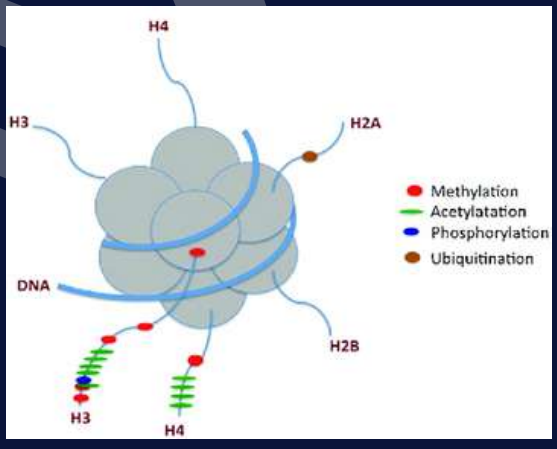

Fig 4: *A diagram of histone modification*

Finally, non-coding RNA is a type of nucleic acid that attaches to coding RNA in order to control gene expression. Because coding RNA is used to make proteins, non-coding RNA can also prevent coding RNA from being used in the production of proteins. Not only that, but non-coding RNA can also use proteins to alter histones. ("What is Epigenetics?", 2020).

HOW DOES GROWTH CHANGE EPIGENETICS?

As we grow, embryonic cells start with one master DNA genome, with all its genes activated or deactivated. This splits into the roughly 200 different cell types that exist in our body such as heart and liver cells, and though they all name the same genome, they all carry individual epigenomes (Ennis, 2014; Guerrero-Bosagna, 2016). Epigenetic markers also exist to control the differentiation of cells. An example is for a marker to turn on the genes to make the proteins into muscle cells while turning off the genes for nerve cells (Shaw, 2017; "What is Epigenetics?", 2020). This explains why genetically identical twins can grow up differently, as growth causes epigenomes to diverge (Guerrero-Bosagna, 2016).

HOW DOES INHERITANCE FIT INTO EPIGENETICS?

In theory, most epigenetic marks are erased with the formation of egg and sperm cells. However, the marks that survive are passed onto the next generation, which is how they are inherited. It is possible to gain epigenetic markers not just from our parents but also from our grandparents (Shaw, 2017; "What is Epigenetics?", 2020).

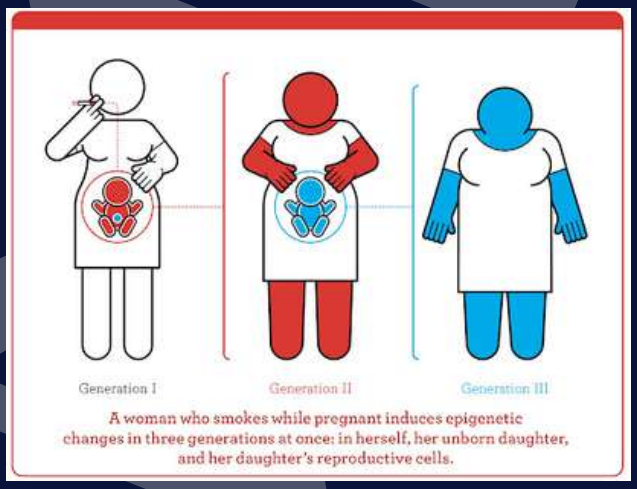

Fig 5: *A poster on the effect of epigenomes on inheritance*

Epigenetics are not permanent, however, as physical changes to our lifestyle can help affect the amount of methylation that takes place in our DNA. An example of this is when quitting smokers saw an increase in the DNA methylation of a gene that is expressed in smokers, though the length of time for our DNA to change depends such as the time period of smoking and the length of the time period before quitting ("What is Epigenetics?", 2020). By having a healthy diet and limited exposure to toxic elements, it is possible to have healthier offspring (Guerrero-Bosagna, 2016).

WHAT FACTORS AFFECT EPIGENETICS?

Epigenomes tend to be affected by external stimuli that can be detected by the body, but it's not exactly clear what exact exposures control the mechanisms. Major factors that have been thought of so far include diet, exercise, chemical exposure such as cigarette smoke, medication, and social experiences.

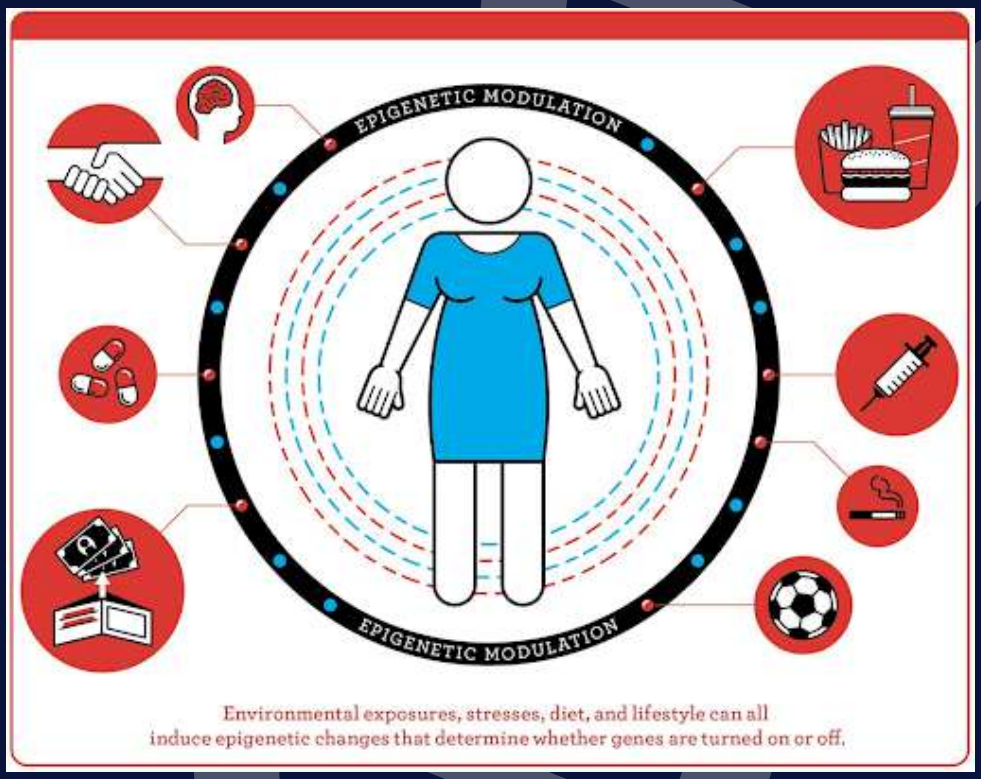

Fig 6: *A poster on epigenome factors*

WHAT FACTORS AFFECT EPIGENETICS?

However, some still doubt the validity of epigenetics, and whether or not epigenetics are the sole way our DNA is read. One argument against this is that evidence also concludes that mammal cells have 2 cycles of demethylation during reproduction that strip nearly all methyl groups and genetic information from the germ and embryonic cells. Because no epigenetic information can survive, there may be nothing to pass on (Shaw, 2017).

Not just that, but testing for epigenetics in families through multiple generations is nearly impossible. This idea comes from multiple people in Sweden and the Netherlands, where starvation and famine in the 1940s that lead to nutrient deprivation now cause obesity, diabetes, schizophrenia and cardiovascular problems. Because a methyl group was added to babies born to mothers who were starving, it makes a gene that decreases metabolism (Ennis, 2014; Zimmer, 2018; "What is Epigenetics?", 2020). However, change needs to be shown through all generations, which is too long for any researcher as even the scientists that carried out this study only tested descendants and not ancestors (Shaw, 2017).

CONCLUSION

In conclusion, epigenetics are a vital part of our health that connects behaviour and environment to inheritance and genes. The reason why epigenetics are so important to science, is that they can explain development, ageing, cancer, heart disease, mental illnesses, addiction and many other illnesses. Furthermore, they can possibly lead to a future where scientists can understand what changes matter through genome editing, and make those changes in people to improve health and wellbeing.

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Fig. 5 A poster on the effect of epigenomes on inheritance. (2017). [Image]. Retrieved from https://www.harvardmagazine.com/sites/default/files/img/article/0417/hm_mj17_rn_1-1.jpg

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STRESS: A BIOLOGICAL PERSPECTIVE

Hannah Wu 11D

WHAT IS STRESS?

In the developed world, stress is one of the most prominent mental health concerns in both adults and adolescents. While many tie stress to pressure from school or work, stress is a normal human response that is hardwired into the human body. ("Stress: Signs, Symptoms, Management & Prevention", 2021) Essentially, stress is physical and emotional tension created by the inability to cope with mental pressure. It is often triggered during incidents that are new and unexpected or when we feel we have little control over a situation. ("Stress", 2021)

Stress has two different forms: Acute and Chronic.

Acute stress is a quick and short term stress response to stimuli, usually felt during traumatic or very serious incidents, or immediately thereafter. A hallmark of acute stress is how soon the stress symptoms disappear, usually within days, if not hours. (Knott, 2021) Chronic stress is a little more familiar to most- a constant state of stress that puts prolonged pressure on the body. It can be overwhelming for many people who are working high stress jobs or facing pressure from their peers and relationships, particularly in the long run.

HOW DOES IT AFFECT THE BODY?

Endocrine System

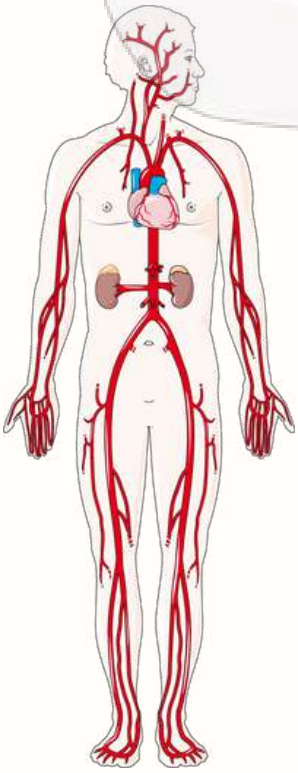
When the brain perceives a threat and the body experiences stress, the hypothalamic-pituitary-adrenal (HPA) axis increases in the production of steroid hormones called glucocorticoids, acting as a primary driver of the endocrine stress response.This includes cortisol, often referred to as the “stress hormone”, which shuts down functions that are non essential to a stressful incident. (Cassoobhoy, 2020). In acute stress responses, this allows the body to defend itself against threats, but in chronic stress, it can lead to cortisol dysfunction, a risk factor for atherosclerosis, if cortisol product is not regulated. (Yao et al., 2019)

In the adrenal gland, norepinephrine and epinephrine (also known as Noradrenaline and Adrenaline) are also released. These two hormones play a vital role in the fight or flight response, which is triggered by stress receptors: Epinephrine affects blood sugar levels and heart rate, and acts to increase effectiveness of respiration; Norepinephrine also has similar effects, but narrows the blood vessels to increase blood pressure as well. ("Epinephrine vs Norepinephrine: Function, Uses, Deficiency, and Excess", 2021)While in the short term these effects can be advantageous for combating stressful situations, in the long term the narrowed blood vessels and high blood pressure can cause hypertension.

Nervous System

There are two main functions or responses to stress in the autonomic nervous system: Sympathetic and Parasympathetic. The sympathetic aspect of the nervous system focuses on the more active approach of the fight or flight response, aiding certain systems and increasing activity in particular areas of the body. The Parasympathetic focuses on the opposite, working to reduce certain functions, to rest, slow down and save energy for the body. ("Chronic Stress, the Nervous System, and How to Manage the Symptoms", 2019) During times of stress, the sympathetic

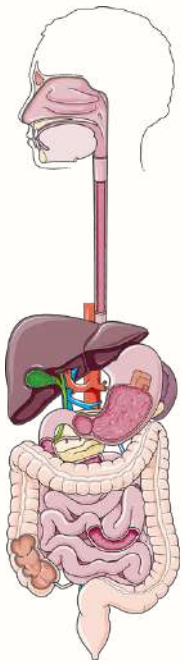
nervous response largely dominates over the parasympathetic system, which causes the body to stop prioritising to rest and renew itself. This is unhealthy and very harmful to the body, as it eventually leads to physiological changes under unrelenting stress, such as insomnia, fatigue and major clinical depression. (Knott, n.d.)



Cardiovascular System

As previously mentioned, due to the secretion of epinephrine and norepinephrine, along with cortisol, certain reactions are triggered in the cardiovascular system. In particular, cortisol can cause Cushing Syndrome, which is caused when an excess amount of cortisol is produced and let into the bloodstream. However, because Cushing syndrome is a rare disease, it's more likely that cortisol dysfunction can cause other side effects, such as stress eating. ("How Stress Can Make You Eat More -- Or Not At All", 2020) High levels of cortisol from long-term stress can also increase blood cholesterol, blood sugar, and blood pressure. ("The relationship between serum cortisol, adrenaline, blood glucose and lipid profile of undergraduate students under examination stress", 2021) If the body experiences chronicstress, this increases the risk for heart attack and stroke.

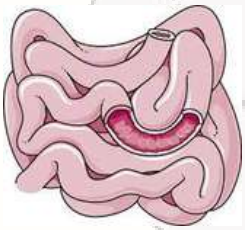
Gastrointestinal System



Part of the stress response system includes slowing or shutting down non essential functions in the body. Unfortunately, digestion is one of these metabolic processes that are slowed and affected by the stress response. In the short term, this benefits the body, allowing more energy to be diverted towards escaping or combating the threat causing stress. However, with chronic stress, digestion can be heavily affected, leading to some serious symptoms.

To understand how this works, the gut actually has a network of neurons that are lined around the gastrointestinal tract. This is known as the enteric or intrinsic nervous system. These nerve cells regulate digestive processes, and when faced with stress, can change how the body digests food. (Iliades & Sassi, 2021) In recent years, there has been more and more evidence showing a significant and strong brain-gut connection (also known as the brain-gut axis) in humans. ("The Brain-Gut Connection", 2021)

In some people, stress can cause diarrhoea. (Davidson, 2021) When the brain perceives a threat, the gut and the intrinsic nervous system can respond by releasing hormones that slow digestion in the stomach but speed up digestion in the intestines, leading to diarrhoea. (Eagle, 2020)



Apart from the gut, stress also affects other parts of the digestive system. Higher up, stress is known to cause problems in the stomach and oesophagus. Some symptoms and conditions that are correlated to stress include heartburn and acid reflux. It is important to note that although stress does not cause these conditions, they act to worsen the symptoms in the body. A study from 2008 found that stress made their subjects become more sensitive towards acid exposure, which would worsen their perception of the pain caused by acid reflux or heartburn during stressful situations. (Fass et al., 2008)

Stress eating is also one of the psychological symptoms that can be caused by stress and lead to digestive problems. When cortisol is released, the body believes that it needs fuel to fight whatever threat is causing the stress, and can cause cravings for fatty, salty and sweet foods. ("Why stress causes people to overeat - Harvard Health", 2021)

Immune System

Perhaps one of the most well known but less discussed aspects of stress is its impact on the immune system. Sadly, the immune system simply cannot be overlooked when it comes to stress: a weakened immune system acts as a gateway for the body to be overtaken by numerous diseases that can wreak havoc in all the other systems.

As part of the immune system, there are two types of white blood cells in the bloodstream: lymphocytes and phagocytes. (Eldridge, 2021) There are also two types of lymphocytes: B-cells and T-cells. B-cells create antibodies to destroy invading pathogens; while T-cells lock onto pathogens, multiply and destroy bacteria or viruses, helping to regulate the immune response. However, when the endocrine system releases the stress hormone corticosteroid, it lowers the amount of lymphocytes in the bloodstream, effectively weakening the immune system. (McLeod, S. A., 2010)

A study from 1984 measured the number of T-cells in medical students from one month before and during their exams, assuming that the first would have students with lower stress compared to the latter. They found a correlation between the level of stress and number of T-cells found in their blood samples, and reached the conclusion that stress played a role in a weaker immune system. (Kiecolt-Glaser et al., 1984) ("Stress Weakens the Immune System", 2021)

In addition to the biological weakening of the immune system, behavioural changes as a psychological response to stress should also be taken into account: stress eating, smoking, drinking and engaging in significant risk-taking habits are commonly found in chronically stressed individuals.

CONCLUSION

As stress is an emotion we usually feel in the face of a negative situation, it carries some negative connotations- although there are some positive instances of stress. For example, stress can help us stay alert and raise our awareness of dangers and threats, increasing our focus, motivation and productivity. The key to stress management is to use stress in a productive and effective way- making sure that stress doesn't affect the body in the long term.

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IMAGE CITATIONS

THE TWISTY TRUTH BEHIND BALANCE

Airi Tachino 11D

A PREVIEW INTO HOW WE MAINTAIN OUR POSTURE AND WHY WE EXPERIENCE DIZZINESS

When you think of dizziness, you often associate it with the mere sensation of light-headedness. But dizziness is more than that. In fact, there are many different types of dizziness, each associated with a different organ system and with a wider range of symptoms (Pressman, 2021). Among the most common types is vertigo, the feeling of being "off-balance" or "seeing the world spin". This often leads to nausea, and even deafness (K. Metzger, 2020). The eyes and brain would be the expected suspects; however, many cases are caused by an unusual source - our ears, and the small crystals they contain, responsible for our sense of balance and gravity. They detect motion and maintain composure, a critical component of our vestibular system (E. Hawkins, n.d.).

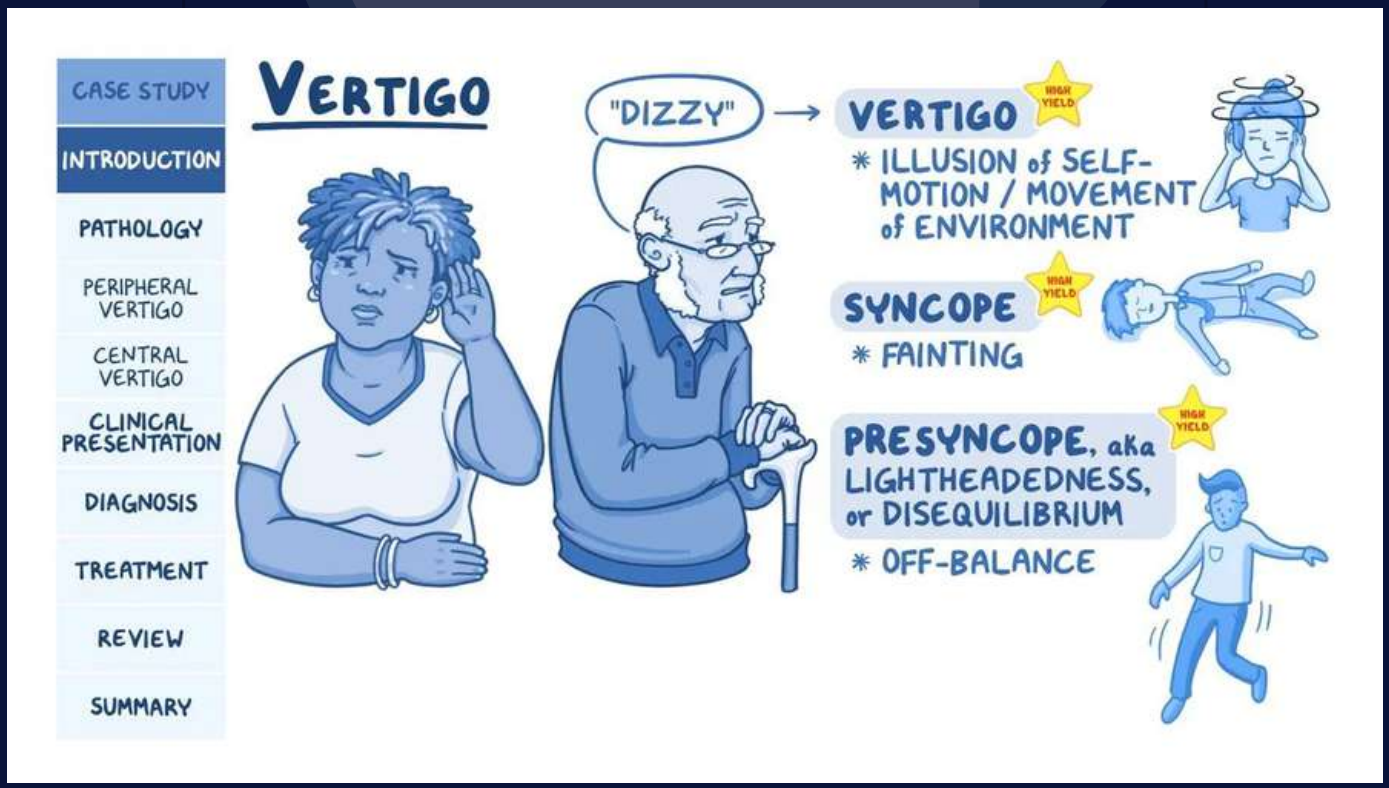

Fig 1: *Vertigo*

OUR INNER LABYRINTH

For this topic to be explored, it is necessary to understand the ear's structure. Our ears have an extremely complicated anatomy; the visible outer ear, or the Pinna/Auricle, are connected to the insides by a channel called the external alimentary canal. This leads up to the Tympanic membrane, better known as the eardrums. The eardrums are the exterior of the middle ear, or the Tympanic cavity, composed of the three ossicle bones - the malleus, incus, and stapes - to send sound waves. This transmission goes further in through the Eustachian tube, where the inner ear is located ("Anatomy and Physiology of the Ear", 2021). Our postural equilibrium is retained within the inner ear, which is the area of interest and pertinence for this article.

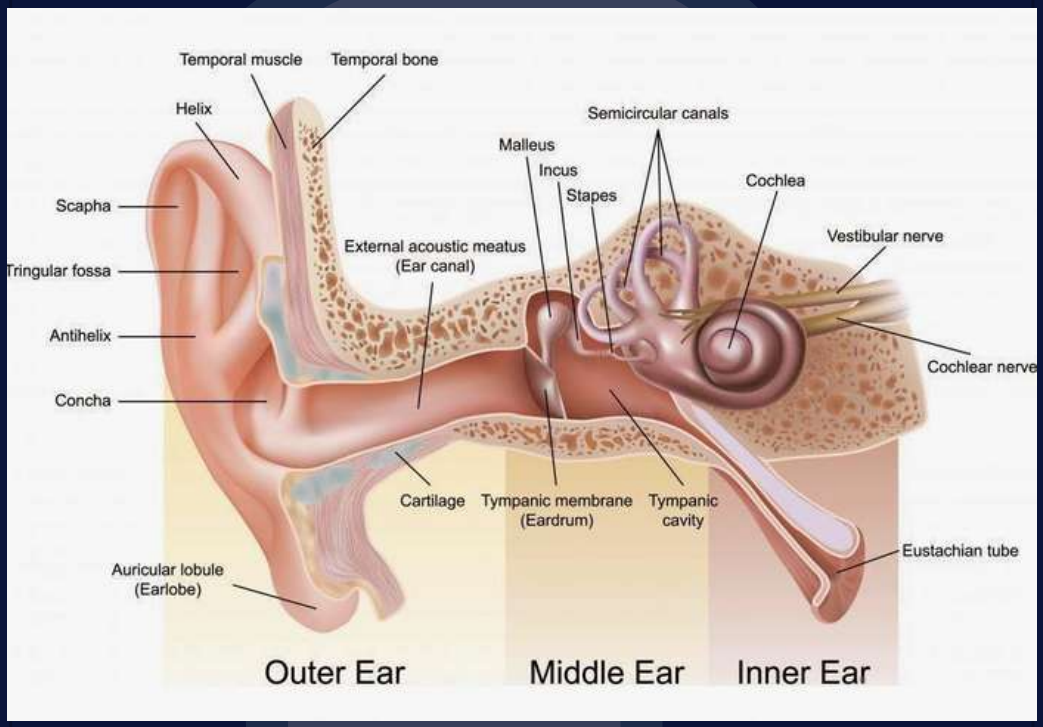

Fig 2: *Ear Anatomy*

The inner ear's main components are the bony and membranous labyrinth, each helping to convert the sound waves received through the previously-described channel into electric neural signals using its mechanoreceptors (Davies, 2020). The cochlea, vestibule, and semicircular canals compose the bony labyrinth; the cochlea is the main snail-shell-like structure of the inner ear, built from the scala vestibuli, scala media and scala tympani (Bruss & Shohet, 2021). On the other hand, the membranous labyrinth is composed of the utricle, saccule, and semicircular duct (Khan & Chang, 2013). The scala vestibuli and scala tympani is lined with perilymph, whilst the membranous labyrinth and scala media contains endolymph, both of which are similar fluids but differentiated by its concentration of Sodium, Potassium, and Calcium ions (K. Pugsley & J. Curtis, 2015).

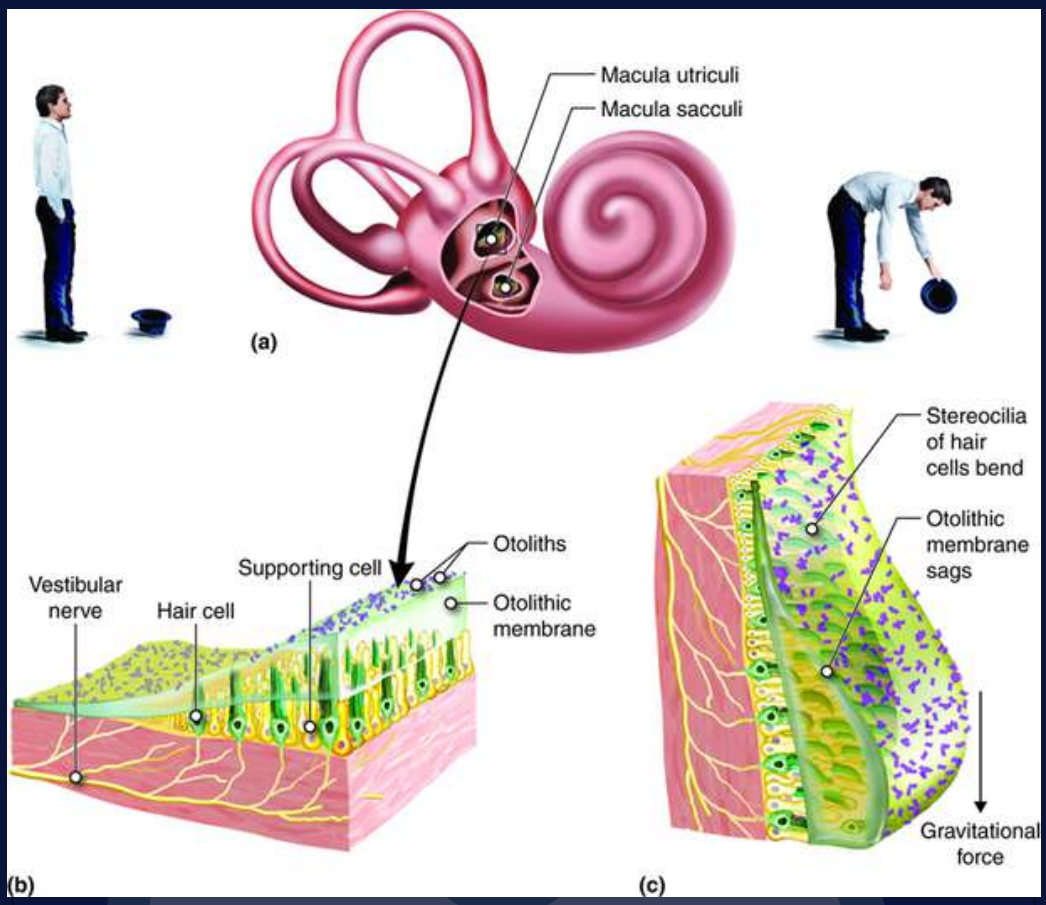

Fig 3: *Inner-ear anatomy and otoconia placement*

CRYSTALS IN OUR EARS, AND THE MANY UNRAVELLED MYSTERIES

Ear crystals, or 'ear stones' in certain foreign languages, are a literal phrase describing the crystals in our inner ear complex, scientifically known as otoconia. Ranging from 3-50µm, they are microscopic calcium carbonate polymorphs ("Polymorphism", n.d.), able to morph into the arrangement of calcite, argonite, vaterite, and/or calcium carbonate monohydrates (Mulligan & Gauldie, 1989). They are held together by proteins, one of them being otolin-1; otolin-1 is a part of the C1q group of proteins, which specialise in functions such as biomineralization. Moreover, research using foetal mice has shed light on the likely formation process of these otoconia - an organic hexagonal base is supported by proteins, while crystallites grow in mosaic-arrangement along the base. Despite the exact process still being unknown, it is supposed that the crystallites form around a central core on the base - determining the size of the otoconia product - whilst simultaneously being coated and linked by organic material (D. Ross & G. Pote, 1984).

These ear crystals are located in the utricle and saccule of the inner ear. They are connected by the underlying gel layer - the otoconial membrane - allowing it to form a 'otoconial mass'. The otoconial mass adds weight onto the inner-ear hair cells - composed of hair bundles made by stereocilia and one kinocilium, and a mass of neuroepithelium respectively -

causing the whole system to be sensitive to gravitational movement. Although this may make the otoconia sound simply like deadweight, both in-vivo and in-vitro experiments have proven that otoconia are asymmetrical, supporting the idea of their possible piezoelectric traits. This means the crystals can pass electricity through themselves when there is weight or pressure introduced, also making them susceptible to change in shape.

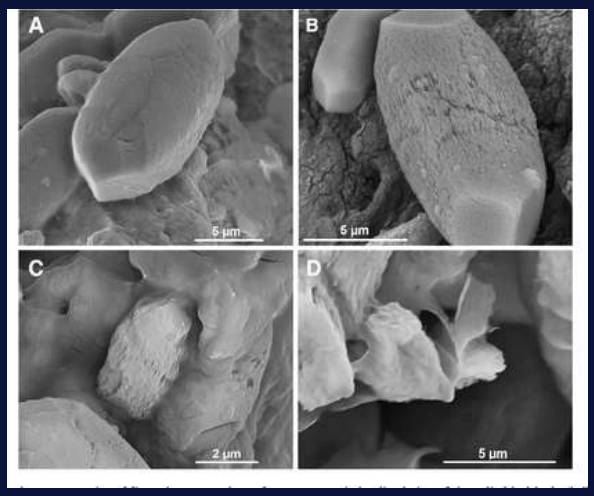

Fig. 4: *Electron microscopy of intact otoconia particles*

Research has also shown how the proteins within the otoconium complexes conduct calcium-ion binding processes, in order to allow the otoconia to morph and stabilise its shape. Combined, these factors allow estimation of otoconial ability to detect linear acceleration and position/movement of our head - there are two ways the otoconia do this. The first method is what has been mentioned previously - gravity pushes and bends the crystals on the hair cells down, causing this acceleration due to inertia to be sent as neural signals, which goes through vestibular nerves to the CNS (central nervous system). The otoconia in the utricle detect horizontal acceleration, whilst the otoconia in the saccule detect vertical acceleration. The second, theoretical method is how they send the information gathered from the calcium-ion binding process through signal transduction. Using its piezoelectric nature, it transduces the movement producing changes in the electric field, which then forms as neural signals rather than relying on the bending of the hair cells (D. Ross & G. Pote, 1984). The signal then goes to the CNS through the vestibular nerves, which tells us our orientation. Regardless, otoconia work with the endolymph (which sends information on rotation strength and direction), allowing us to ultimately maintain balance (The vestibular system, balance, and dizziness, 2015).

CARING FOR YOUR EAR CRYSTALS TO AVOID GETTING A STROKE

Sometimes there is an abrupt shift in equilibrium, which is then aggravated further from movement such as heavy exercise or stretches, causing the otoconia to be displaced out of position. The movement induces the otoconia to fall into the endolymph fluid, which produces incoordination between what is seen versus what is sensed ("Why Loose Ear Crystals Make You Dizzy and How To Fix Them", 2021). Fortunately, the displaced otoconia dissolve naturally in the endolymph after a few weeks ("Benign Paroxysmal Positional Vertigo (BPPV)", 2019).

Otoconia that is out of place can cause disorders such as BPPV (benign paroxysmal positional vertigo). This is rather common, and although there is research indicating an increased risk of getting an ischemic stroke when having BPPV (Choi & Kim, 2021), in most cases they heal within time. Moreover, by conducting the Epley manoeuvre - a simple exercise consisting of head-tilts - the otoconia crystals shift back into their correct place, resolving 90% of all BPPV cases with no harmful side-effects (Biggers, 2017). However, as the symptoms of BPPV and a stroke are almost identical, doctors advise patients to seek medical attention if it occurs.

BALANCE - THE NEXUS OF RESEMBELANCE

The presence of otoconia has been found not just in humans, but in most vertebrates. Fish also have similar mineral deposits called otoliths, which are alike in structure but bigger and located in different parts of their bodies - even fish lacking bones or jaws such as the agnatha (containing a unique spherical otolith) have it.

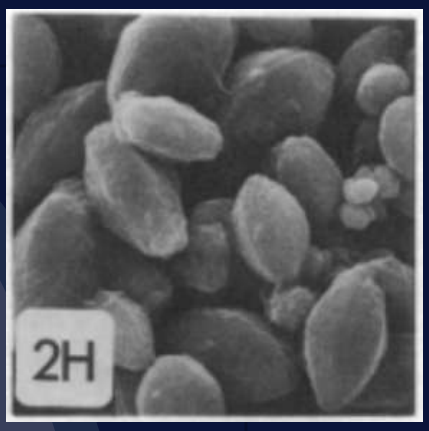

Fig. 5: *Electron microscopy of an Cephaloscyllium isabellum (Draughtsboard shark) otoconia*

Several shark species were noted to have homogenous, or similar, otoliths (Mulligan & Gauldie, 1989). And despite how crustaceans lack otoconia and otoliths ("The Otocysts of Decapod Crustaceans", 1901), they have a mineral deposit called statolith.

Recent research on dogs have shown that they also experience conditions sharing likeness to BPPV; peripheral vestibular disease is a common illness in elderly canines ("Treating older dogs with vestibular disease", 2019) - similarly, conducting a modified Epley manoeuvre on the affected dogs have been noted by veterinary literature to usually succeed in treating it ("Physiotherapy management of geriatric vestibular disease", n.d.).

CONCLUSION

There are still many unanswered questions regarding the development and mechanism of our ear crystals. Depending on the source referenced, the names of these ear crystals may differ, as some sources use the terminology of 'otoconia', 'otolith', and 'statolith' in a way which points to the same structure. However, what can be said is how these ear crystals - whatever they may be called - seem to exist in every living organism, and may be the cause of more types of dizziness than we already know.

GLOSSARY

Vestibular system - the organ responsible for sensing and sending information so we can move to maintain our balance

Eustachian tube - the passage connecting the middle-ear to the throat

Mechanoreceptors - a receptor able to sense mechanical stimuli such as pressure

Polymorphs - crystalline substances able to exist in more than one form

Stereocilia and kinocilia - hair-like receptors able to detect sound and balance

Neuroepithelium - nervous stem cells which can specialise to conduct specific functions

In-vivo and In-vitro - experiments done in and out of an living organism respectively

Signal transduction - communication conducted by cells in order to pass on biological information from one cell to another

Ischemic stroke - when the artery leading to the brain clots, causing the blood vessel to narrow or be blocked, leading to a stroke.

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Fig. 3: Vestibule Gyro and Accelerometer Triads, by evolution, or design? [Image] Retrieved 5 January 2022, from https://reasonandscience.catsboard.com/t3131-vestibule-gyro-and-accelerometer-triads-by-evolution-or-design?fbclid=IwAR286ZlnlR3oZ7xMeVOsZJe8ne82JYYcY4j1rZqoUCXyi6h5UEAEGi-mWhE

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From Kant's Metaphysics to Einstein's Physics: On the Relationship Between Space and Time

Kin Ching Ip 11N

INTRODUCTION

Can time exist outside of space? Or can space exist outside of time? From ancient Inca philosophy to Aristotle to Leibniz and Newton, great thinkers in history across the globe attempted to provide an answer to this question. It is a fundamental question which neither physicist nor metaphysician can avoid in their studies. To analyse the different approaches to and answers to this question, this essay will explore thoughts from metaphysician Immanuel Kant and physicist Albert Einstein.

This essay will comprise of 3 main parts: Part one will explain Immanuel Kant's theory to prove the interdependence between time and space, using the framework of epistemology in his work *A critique of pure reason* (Kant, 1787). Part two will explain Albert Einstein's proof for the concept of space-time, using his theory of relativity and his thought experiment of the train. Part three will then conclude this essay by analysing the similarities and differences between Kant and Einstein's approach to answering this question: What is the relationship between space and time?

PART ONE: IMMANUEL KANT

Immanuel Kant, a Prussian philosopher, was one of the most influential thinkers of enlightenment and western philosophy. To understand his philosophy on space and time, we must first understand his comprehensive and systematic structure of philosophy. These are some very basic Kant philosophical groundings to understand this essay: Some knowledge comes from experience, whilst others exist inherently and intuitively, transcendent of experience. The former is referred to as *a posteriori;* whilst the latter is referred to as *a priori*. (Kant, 1787) Perception is a representation with consciousness. Sensation is a perception that only relates to the subject as a modification of its own state, entirely subjectively (for instance, the sensation of pain in a subject's body is subjective) (Gracyk, 2009)

I. PROVING THE EXISTENCE OF TIME USING SPACE

Our understanding of space comes from external intuition, which we experience and observe empirically from the exterior, objective world. (Weinert, 2005) Space is proven to exist by our experience because our current state of existence occupies space. This type of external intuition is phenomenological, perceived by sensory experiences.

When space allows phenomena to occur, it must then occur through the dimension of time. This is because to sense something, to have sensory *experiences*, time must exist. For instance, we cannot possibly feel pain (a type of sensation) if time has stopped. Sensation must be continuous. All phenomena are perceived by sensation, therefore phenomena – and the space which the occurrence of phenomena occupies – must also be continuous. To be continuous is through a period of time. Hence, the concept of time must exist when space does. (Kant, 1787)

II. PROVING THE EXISTENCE OF SPACE USING TIME.

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PART TWO: ALBERT EINSTEIN

Einstein proved a union of space and time, which he calls “space-time”. Space-time theorised a 4-dimensional world, which incorporated time as one of the dimensions. To understand Einstein’s theory of space and time, it is necessary to understand Einstein’s two postulates.

The first postulate is that laws of physics are the same in all inertial reference frames. (Martin et al, 2020) For example, Brice is sitting still on a train leaving the station in acceleration, he will be observed as moving by Alice who is standing still on the station. In this case, the station is the “inertial reference frame”; whilst the moving train is the “non-inertial reference frame”. Brice cannot detect his movement. (Dirks & Sharma, 2012) However, he can detect the fact that he is on an accelerating train by perceiving a backward force pushing her back to his seat. This force is known as a Fictitious force. (Scientific American, 2007)

The second postulate is simply that the speed of light c is always constant, for anywhere in the universe. , independent of whether or not it is observed through an inertial or non-inertial reference frame. In other words, the speed of light is the same for Brice and Alice, regardless of their relative motion. (Martin et al, 2020)

II. PROVING THE EXISTENCE OF SPACE USING TIME.

Continuing with Alice and Brice’s example. Imagine Alice is standing in the middle of a train station, 20 metres apart (Figure 1). Two clocks, clock A and clock B are present on two ends of the station, respectively at 0m and 20m. Each clock will emit a beam of laser light towards Alice at the same time. As Alice is standing at the midpoint of the two clocks, she will see the two beams of light arriving at her location at the same time. She will raise her hands when she observed that situation.

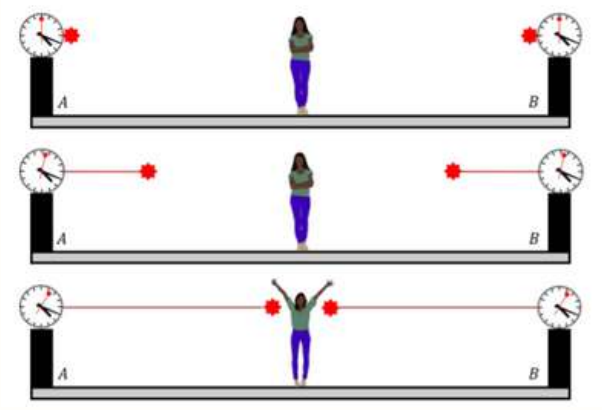

Figure 1.
Alice is standing in the middle of 2 clocks that emit a laser beam (Martin et al, 2020)

Brice is sitting on a train travelling at a constant speed from clock A to clock B (Figure 2). Therefore, he sees Alice and the station moving towards him. From Brice's perspective, once clock A emits the laser light, Alice moves towards clock A (because Brice's train came from the direction of clock A); once clock B emits the laser light, Alice moves away from clock B (because Brice's train is heading towards clock B). Brice observes that the distance between light beam A and Alice to be shorter and shorter, and distance light beam B and Alice to be further and further. As the speed of light is always constant (according to Einstein's second postulate), then Brice will observe that light beam A travels a shorter distance to reach Alice in comparison to light beam B.

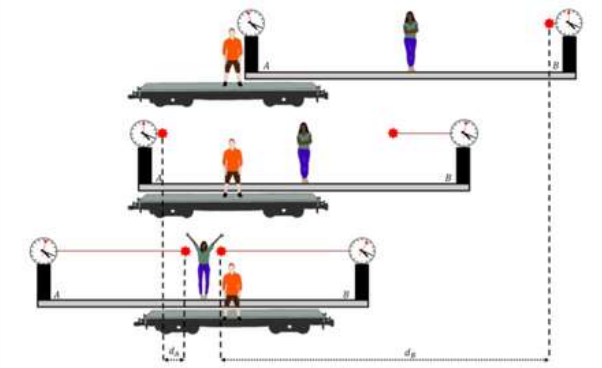

Figure 2.
The relative motion between Brice and Alice (Martin et al, 2020)

For Brice to agree that Light beam A and B arrive at Alice's location at the same time, Light beam B has been emitted first; in this scenario, Alice will not agree that both light beams arrived simultaneously. Brice and Alice cannot agree on the occasions which Light beam A and B will reach them simultaneously. Thereby concluding: the dimension of time cannot be separated from the three-dimensional space. (Martin et al, 2020)

II. PROVING THE EXISTENCE OF SPACE USING TIME.

It is relatively simpler to prove: the relative motion between Brice and Alice cannot be observed by either of them if time didn't exist. Space cannot exist outside of matter and energy. (Odenwald, 2017) From empirical observations, energy is always in the process of transferring. The transfer of energy than causes the change of matter and gravity ($\Delta PE_g = mgh$). This process of transfer of energy always occur through the dimension of time. Thereby also concluding: the three-dimensional space cannot be separated from the dimension of time.

PART 3: CONCLUSION

In conclusion, both Kant and Einstein took a very similar approach in explaining the relationship between the three-dimensional space and time. From both Kant's argument of phenomena and noumena of existence and Einstein's thought experiment, it is proven that not only are 3d-space and time interdependent, but also the fact that objective space can be altered through the subjective time, depending on the difference in frame of reference.

To reach the same conclusion, Einstein takes a more mathematical approach. He establishes the thought experiment of the train, and through observing the interdependent relationship between time and space, he works out the reasons behind the intuitively contradicting outcome mathematically. He then comes to the conclusion that time is not absolute, but dependent on the observer's frame of reference.

Kant takes the traditional metaphysical approach by making the presumption that time is subjective. This presumption is made from his abstract, yet systematic and self-consistent structure of philosophy. From presuming time is subjective and space objective, Kant then works out their interdependency, which Einstein observed as the first step in his thought experiment.

Moreover, the development from Kant to Einstein, from metaphysics to physics, characterised the inseparable relationship between science and philosophy; Kant's theory of space and time is a fine example of philosophy acting as an analytical hypothesis, awaiting to be proven empirically by Einstein's relativity theory. As Einstein put it, "Science discovers, philosophy interprets."

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Martin, R.D., Neary, E., Rinaldo, J. and Woodman, O. (2020). Figure 24.2.3 : Alice is equidistant from two clocks. The clocks fire a laser pulse when the time is 20 past four, and Alice observes both pulses arriving at her location at the same time, concluding that the pulses were emitted by the clocks at the same time. [Image]. Introductory Physics - Building Models to Describe Our World. https://phys.libretexts.org/Bookshelves/University_Physics/Book%3A_Introductory_Physics_-_Building_Models_to_Describe_Our_World_(Martin_Neary_Rinaldo_and_Woodman)/24%3A_The_Theory_of_Special_Relativity/24.02%3A_Einstein%E2%80%99s_postulates.

Martin, R.D., Neary, E., Rinaldo, J. and Woodman, O.(2020). Figure 24.2.4 : Brice is on a moving train, and, from his perspective, it is Alice and the platform that are moving towards him. Brice must conclude that the pulse from clock B was emitted earlier, since it must travel further than the pulse emitted from clock A to reach Alice at the same time. [Image]. Introductory Physics - Building Models to Describe Our World. https://phys.libretexts.org/Bookshelves/University_Physics/Book%3A_Introductory_Physics_-_Building_Models_to_Describe_Our_World_(Martin_Neary_Rinaldo_and_Woodman)/24%3A_The_Theory_of_Special_Relativity/24.02%3A_Einstein%E2%80%99s_postulates

BACTERIOPHAGES AN ALTERNATIVE TO ANTIBIOTICS?

Hei Ching Tang 12W

INTRODUCTION

In recent years, antibiotic resistance has become an increasingly concerning crisis in the healthcare systems of many countries. As a result of genetic mutations, the drugs that initially kill infectious bacteria gradually lose their effectiveness as these bacteria evolve into superbugs, having resistance to multiple antibiotic drugs. More and more lives are lost to these deadly superbugs that cause diseases that are very difficult to treat. However, a new therapeutic method has been gaining more attention lately which could provide an alternative treatment option to combat bacteria: bacteriophages.

WHAT ARE BACTERIOPHAGES?

Bacteriophages or "phages", in a nutshell, are viruses that target and kill bacteria. They can be found pretty much wherever bacteria are present, such as oceans, soil, sewage water, your skin and intestines etc, meaning that they are the most abundant biological beings (Paganelli, 2019). The basic structure of a bacteriophage would have an icosahedral protein coat along with a tail and leg-like tail fibres (Rogers and Young, 2018), where the protein coat would protect either a DNA or RNA molecule, similar to the structure of many other viruses. Additionally, they are technically not considered living organisms as they need a host to reproduce and do not perform other living processes.

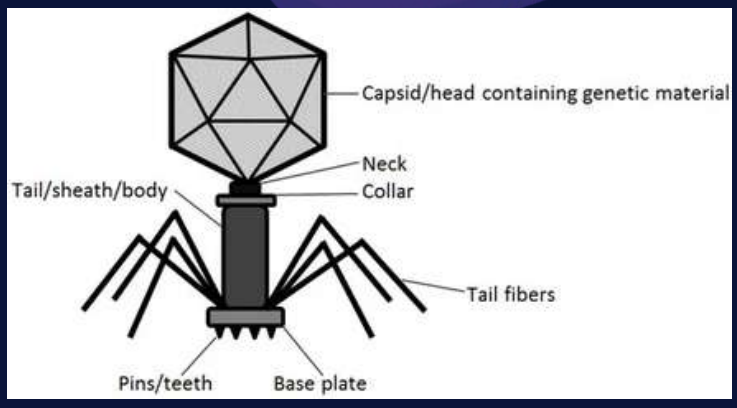

Fig. 1: (Doss et al., 2017)

INFECTION

The key reproduction process of bacteriophages is the lytic cycle, which is similar to how an average virus would infect living eukaryotic cells. Phages attach to the membrane of a bacterium and inject their genetic material inside, which would replicate itself within the cytoplasm of the bacterium.

As a result, the ribosomal organelles used for protein synthesis in the bacteria are converted into factories producing a new set of proteins that make up new phages. The infected bacteria would continue to produce copies until the final stage of the lytic cycle.

This is when the new bacteriophages produce endolysin, an enzyme that forms holes in the bacteria's membrane, causing the organism to undergo lysis and die while releasing the newly produced bacteriophages which can infect other bacteria, repeating the cycle again (Kurzgesagt – In a Nutshell, 2018).

Alternatively, there is the lysogenic cycle where the bacteriophage does a similar process of inserting its genetic material into the bacteria. However, the genetic material integrates itself into the genome of the bacteria rather than targeting the ribosomes. These genetic materials become prophages. The bacterium containing the prophage replicates into new daughter cells that also have it until an external environmental change occurs where the prophages convert back to the process of the lytic cycle and kill all the daughter bacterial cells that contain it (LM and LD, 2021).

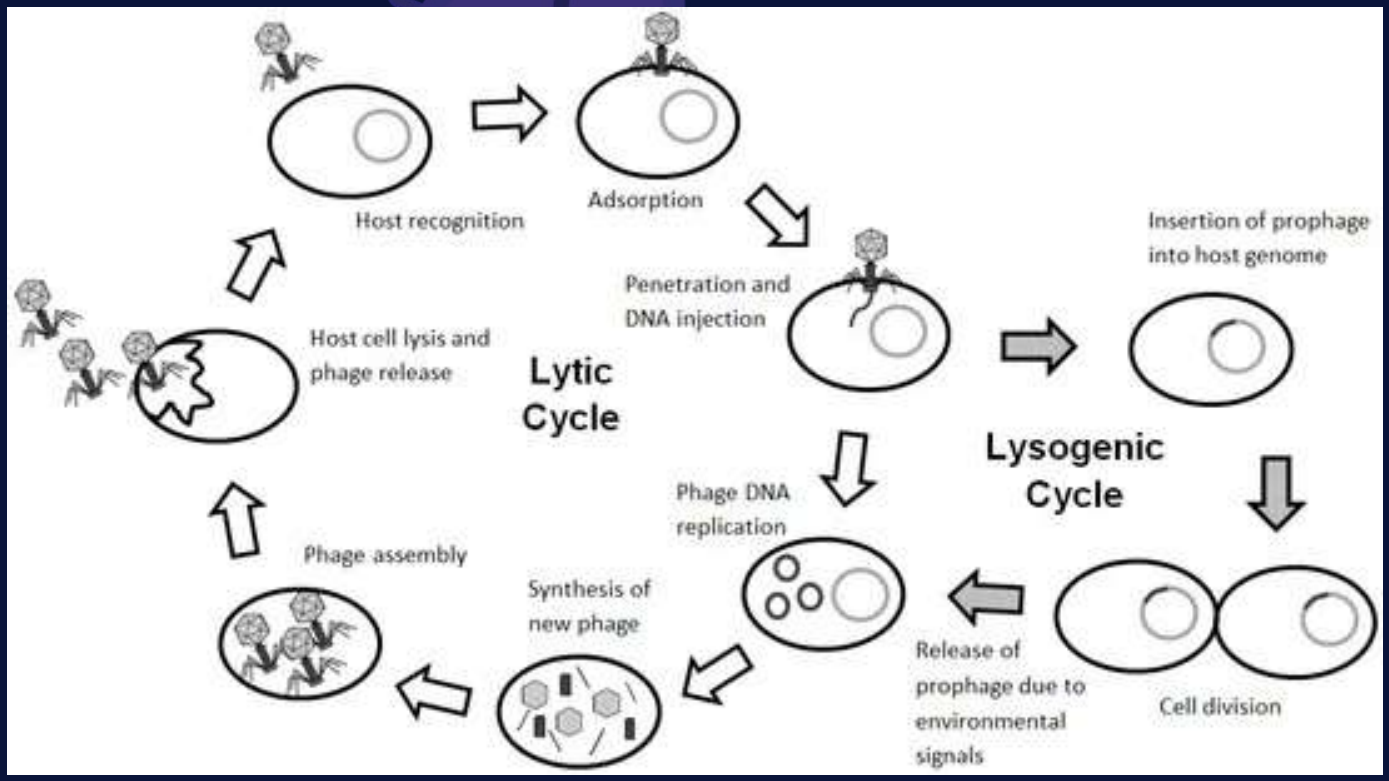

Fig.2: (Doss et al., 2017)

ADVANTAGES OF BACTERIOPHAGES

So, back to the topic of antibiotic resistance, bacteriophages do have key advantages in helping humanity against this growing crisis. Firstly, bacteriophages are target-specific, each type having a different structure that is unique to the receptors of certain bacteria that allows them to bind. Unlike antibiotics, which target a broad range of bacterial species, phages are capable of eliminating harmful bacteria while preserving the beneficial microbes that reside for example in your digestive system (Srisuknimit, 2018). In addition, they will not infect human eukaryotic cells as they are too different from bacterial prokaryotes, meaning that they are generally safe for therapeutic use when it comes to risks of infection.

Another notable advantage of bacteriophages is that they are more cost-effective compared to antibiotics. Very few doses are usually needed to treat infections as phages can replicate on their own while being able to stay inside the body for several days (Paganelli, 2019).

Furthermore, bacteriophages can be used to kill drug-resistant superbugs. The reason why antibiotics work against bacteria is that they disrupt the life processes bacteria need to survive and reproduce. Gene mutations can easily counter these measures. For example, bacteria can produce a structure called biofilm that protects them from antibiotics. Phages contain enzymes that can digest this biofilm (Paganelli, 2019). What makes things better is that they can also mutate and adapt alongside the mutations of their targeted bacteria, making them more flexible in terms of usage and bacterial resistance is less prone to happen (Scott, 2019).

THE CASE OF TOM PATTERSON

There have also been recent triumphs in the use of bacteriophages as seen in the treatment of a 69-year-old named Tom Patterson who is the first patient to be cured with phage therapy in the U.S in 2016. After returning from a holiday in Egypt, Patterson suffered from abdominal pain and fever, being infected by a superbug called Acinetobacter baumannii with pancreatitis - the inflammation of the pancreas.

Fig.3: (Lipman, 2019)

With standard treatments failing, he fell into a coma and was dying. Patterson's wife, Steffanie Strathdee, became desperate as the situation became dire and turned to phage therapy. With help from multiple researchers, in Thornton Hospital at San Diego, a cocktail of four different bacteriophage species was injected into Patterson's bloodstream. Within the span of 4 days, Patterson wakes up from his coma. The recovery afterwards was slow but there was no longer a trace of A. baumannii in his body, and he continues to live a normal life today (LaFee; Buschman, 2017).

LIMITATIONS OF BACTERIOPHAGES

Overall, these are significant advantages. So you may wonder why you might not have heard of them before, and they aren't being utilised as much as antibiotics? The most likely answer was that antibiotics, being first discovered in 1928 as penicillin by Alexander Fleming, was generally more readily available and effective against bacteria up until today, so research for bacteriophages was put aside.

Moreover, the knowledge of bacteriophages we have today is limited and there are still uncertainties with the use of phage therapy. For example, there are concerns about how the immune system responds to and interacts with bacteriophages. In addition, more research is also needed for the genetic engineering of phages in order to find the right sample for a specific bacterial strain (Paganelli, 2019). As a result, the U.S. Food and Drug Administration (FDA) has not yet approved the safety of phage therapy.

CONCLUSION

Bacteriophage therapy really is appealing as a solution to antibiotic resistance. But we have yet to discover more of its potential and mechanisms, while also needing time to normalise their usage and ensure that they are safe for public utilisation. Through further research and testing, it is highly possible that bacteriophages will be more commonly used in the foreseeable future.

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Xenobots, the First Reproducing Robots

Ellie Ham 11R

Robots, known as machines that mimic human activities by following the tasks that were commanded. They are a crucial part of the fourth industrial revolution, and the society we live in would not have been possible without them. When the topic of robots are brought up, most people think of metallic objects with complex mechanisms contained within. However, xenobots, also famously known as living robots, are breaking the common conceptions.

WHAT IS A XENOBOT?

Invented in 2020, xenobots are the world's first robots that are considered alive. These tiny organisms are composed of stem cells from the African clawed frog, also known as Xenopus laevis (Hunt, 2021). Made up of approximately 3000 cells with its size being less than 1 millimetre, these robots are still a new technology with innumerable possibilities due to it's miniscule size and ability to move (Hunt, 2021).

According to its creators, Sam Kriegman, Douglas Blackiston, Micheal Levin and Josh Bongard, xenobots are an entirely new life form, a machine-animal hybrid that can replicate by itself. Although the composition of these tiny bots are from frog cells, it cannot be considered as a frog or a tadpole due to the fact that the design of their anatomy were chosen by numerous computer simulations while the cells acted completely differently from what was known as frog cells (Bawden, 2021). Xenobots are so far the only known organisms that evolved inside a virtual world and not on Earth (Levin, 2020).

Fig 1: *Xenobots (Blackiston, 2021)*

Scientists are especially excited about this new organism as they managed to alter how cells were supposed to originally act. The ability for these organisms to reshape when they're not genome cells are the evidence that intelligence is present in them. They are the first example that scientists have managed to apply artificial intelligence in body cells, which can lead to new studies where computer intelligence is applied to living organisms (Levin, 2020).

HOW ARE XENOBOTS MADE?

Xenobots are created by extracting possible skin and heart muscle cells from fertilized Xenopus laevis embryos. The removed cells are then moved onto a petri dish coated with agarose, a polymer commonly used as a gelling agent, allowing the cells to cure (Kriegman et al., 2021). The cells are modified to a spheroid shape after 4 days of maturation at 14C° (Levin, 2020).

Xenobots that don't use the spheroid shape underwent similar procedures. However, these cells were only incubated at 14C° for 24 hours, and were pressed with 2.62 mg/mm2 force for 3 hours compressing the tissue gently. Then these organisms were shaped manually using tools such as surgical forceps and wire electrodes, later incubated again for 24 hours in 14C° (Kriegman et al., 2021).

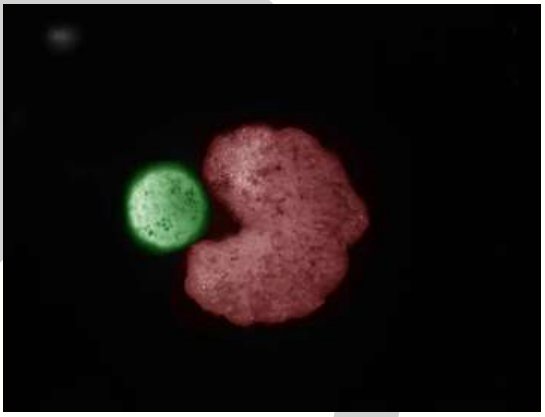

Fig 2: *Xenobot (Blackiston, 2021)*

The stem cells were fused together so that they could re-imagine their unicellular nature (Kriegman et al., 2021) by only altering their cell electricity to dictate what the cells should grow, with no genetic editing involved. Bioelectricity, also known as non-neural electricity, is used when cells communicate with each other, and scientists have found a way to rewrite the processes cells were first supposed to undergo, and change the course of action to what they wish instead. For example, by activating specific electrical patterns on cells, scientists are able to create extra limbs, eyes, or hearts. They used the same method on frog stem cells by altering their bioelectrical patterns, which led to the discovery that the stem cells learned how to repurpose their cilia, originally used to distribute mucus on frog skin, to row against water for movement (Levin, 2020).

HOW DO XENOBOTS 'REPRODUCE'?

The xenobots replicated themselves through kinetic replication, a replication process where raw materials are merged into self-supporting duplicates that are practical. It is theoretically possible for replicators to copy themselves if they are supplied with adequate materials in order to build the designed shape (Levin, 2020).

In the case of xenobots, they required specific conditions in order to replicate kinematically. The scientists placed the stem cells inside a petri dish coated with agarose, then placed 12 adult organisms that aged between 5 to 6 days in 14C° inside the dish.

The stem cells and the organisms are left for approximately 20 hours in 20C° for them to interact with each other. To prevent any errors, the dishes were not moved, while lights were also turned off as the heat produced from the light has possibilities of creating weak convection currents in the dishes (Kriegman et al., 2021).

As these bots took the C-shape that resembled Pac-Man, a popular video game character, they were able to use their 'mouth' as an advantage as they spun around to gather and compact frog cells around them. Offsprings were replicated when the bots later released the compressed cells, and these processes repeated on and on until the xenobots ran out of energy that was provided from their 'parents'. Yet, as the energy that was passed on was limited, the size and number of offspring declined as more generations were borned, and soon completely stopped when the organism was too small to evolve. The offsprings that were born were moved to petri dishes coated with agarose and incubated for 5 to 6 days in 14C° for future research (Kriegman et al., 2021).

However, the shapes of xenobots were not always like this. The original xenobots had a spheroid shape, which scientists later found was inefficient for replicating. Thus, it was eventually discovered that these bots were only able to duplicate in specific conditions and the spheroid shape that xenobots used to have was not suitable for gathering and compressing cells that were required in replications. To solve this issue, the researchers used artificial intelligence to test out various designs to see which shape was the best in the xenobots' 'reproducing' process. After numerous computer simulations on eight NVIDIA Tesla V100s, a graphics processing unit used for speeding up artificial intelligence simulations, the researchers concluded that replications happened most often and efficiently when the xenobots took the current C-shape (Leston, 2021). The scientists emphasised the fact that the shape the xenobots are in is the program, and it is the factor that affects how xenobots behave (Neuman, 2021).

POSSIBLE APPLICATION AREAS

Although xenobots are still a new type of technology that will not be able to be put in use anytime soon, they are an exciting discovery as it opens up innumerable possibilities for many problems that humanity hasn't been able to solve.

For example, xenobots can be used as a scientific tool to study morphogenesis, a biological step that results in cells, tissues or organs developing into specific shapes. Scientists can use xenobots to understand how the cells communicate with each other. Previously, we could not control what cells built. Yet if this information can be learned,

scientists will be able to use this knowledge to rewrite information that has already been written in cells, solving the main problem of biomedicine. If we gain access to this information, we will be able to improve the quality of regenerative medicine as cells will be able to assemble healthy organs, resolve health issues such as degenerative disease, traumatic injury, birth defect and ageing (Levin, 2020).

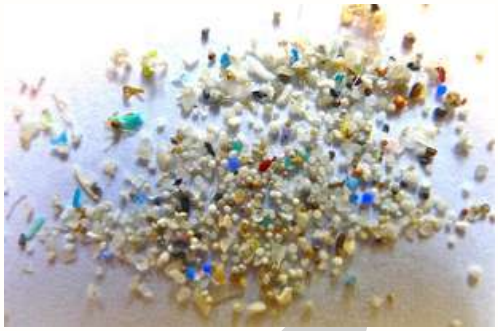

Fig 3: Microplastics (Oregon State Univesity, 2021)

Furthermore, xenobots may be applied for clinical uses, such as reshaping arthritic joints and delivering pro-regenerative compounds to specific parts of the body. There have also been suggestions that these organisms may also be used to treat cancer, by collecting cancer cells inside human bodies. Although these possibilities sound farfetched, scientists have already completed trials with frog models, now ready to move on to experiments using mammalian cells (Levin, 2020).

Xenobots may also be used to clean up microplastics in our oceans. Unlike many modern-day technologies which result in additional pollution, xenobots are biodegradable as they are made up of cells, which will naturally break down once their energy, provided by the parent cell, runs out between the period of 10 to 14 days. Scientists explained that these organisms will effectively collect microplastics in the same way they 'reproduce', gathering particles and compacting them (Levin, 2020).

ETHICAL CONCERNS

Although the invention of xenobots excites many scientists, There are still ethical concerns. Many researchers expressed their worries that we should be cautious when we exploit life to prevent the possibility of the experiment going badly. However, researchers refuted this statement by saying that for xenobots to replicate, stem cells are required, which is not obtainable outside of the lab. Furthermore, they will not be able to evolve or mutate by themselves as no genetic changes have been made (Neuman, 2021).

CONCLUSION

To conclude, xenobots are still a relatively new technology with numerous possibilities. As the first living machine-animal hybrid, it may lead to groundbreaking discoveries that will finally end many of the modern problems.

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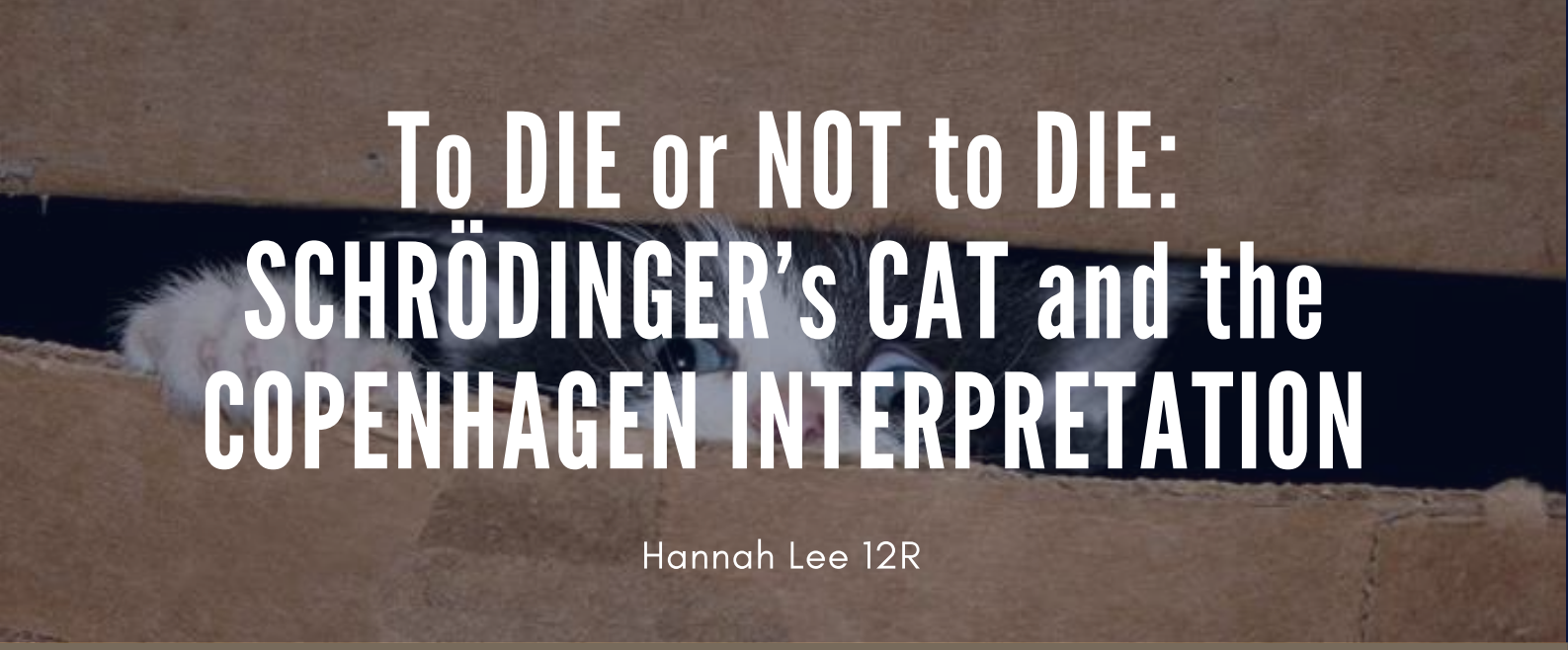

To DIE or NOT to DIE: SCHRÖDINGER's CAT and the COPENHAGEN INTERPRETATION

Hannah Lee 12R

NOTE

This article only covers a small portion of quantum physics as a whole and focuses on the Copenhagen Interpretation and Schrödinger's Cat. To learn more about other theories and the Heisenberg Uncertainty Principle, read Tammi Ip [11R]'s piece!

Quantum mechanics is a branch of physics that explores the peculiar behaviour of energy and matter on an infinitesimal scale. It was first developed in the early 20th century by Niels Bohr and Max Planck after various experiments revealed weaknesses in classical physics. (TED-Ed, 2014) Classical physics refers to the theories that existed before the emergence of quantum mechanics; theories that could describe our world on a macroscopic scale, but became insufficient when applied to the small, subatomic world of quarks and electrons. (Jaeger, 2014)

I. SUPERPOSITION

One of the fundamental theories behind quantum mechanics is superposition, which is the idea that quantum objects can exist in two states simultaneously. This can be put into practice with the wave-particle duality. Wave-particle duality describes how matter can be viewed as both a wave and a particle on the smallest of scales. On a macroscopic scale, particles would be expected to behave like projectiles - much like a pebble or a ball, and waves would behave like ripples on the surface of a lake. However, from a microscopic viewpoint, this difference is blurred. (Muir, 2013)

Electrons showcase this duality in an experiment known as the "Double-slit experiment". If you fire electrons through a board containing two slits onto an optical screen, you would expect to see a light patch on the screen behind each of the slits and darkness everywhere else. This pattern is expected of the particle-like electron, moving in a straightforward way through one, individual slit. (The Feynman Lectures on Physics Vol. III Ch. 1: Quantum Behavior, 2013)

However, the actual pattern that is created is an interference pattern, a pattern distinctive to when waves overlap. This pattern could not be created if the electrons were truly behaving like particles, proving that the wave-particle duality exists and the electrons are passing through both slits simultaneously. This also shows how quantum superposition is happening, wherein the electron is able to exist in two places at the same time. (Muir, 2013)

Bizarrely, this interference pattern disappears if the experiment is changed to detect which slit the electron is passing through instead of the bands on the screen. It reverts back to what is expected of the particles, creating areas of electrons behind the slits and nowhere else. This shows yet another integral component of quantum physics - measurement and the collapse of the wave function. (Veritasium, 2020)

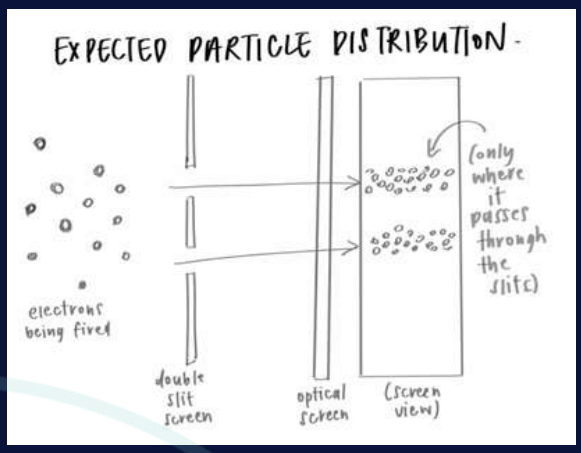

Fig 1.1 *What is expected to happen when the electrons are fired through the slits onto the screen.*

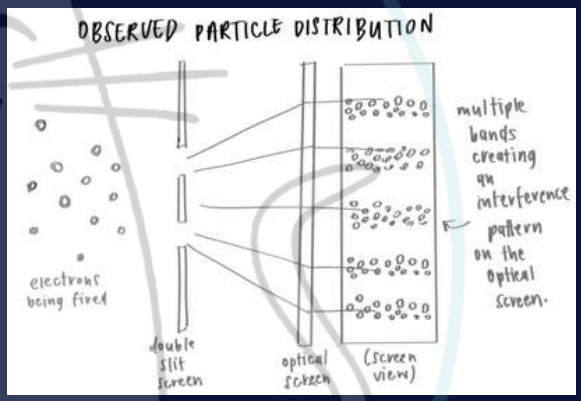

Fig 1.2 *The interference pattern formed when electrons are fired through the slits. Notice how there are multiple bands, rather than just two.*

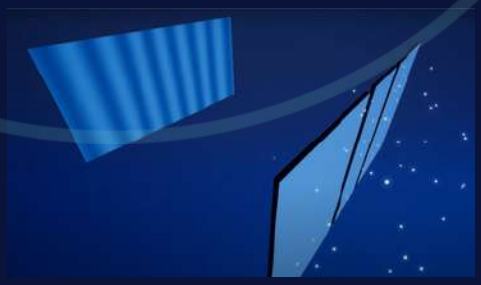

Fig 1.3 *representation of the interference pattern (Veritasium, 2020)*

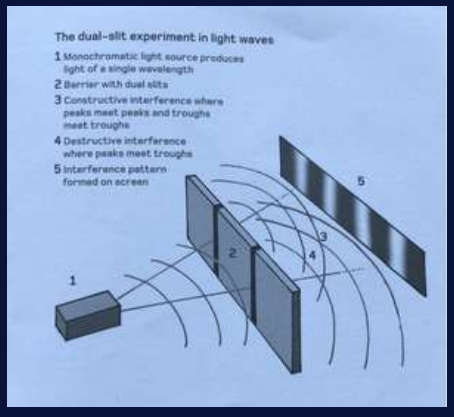

Fig 1.4 The formation of the interference pattern via the dual-slit experiment with light (Muir, 2013)

II. MEASUREMENT

The wave function is a complicated mathematical formula that essentially describes the probability of an electron existing in a certain spot during the double slit experiment. The collapse of the wave function is when the quantum system stops existing as a superposition of states and instead only becomes one or the other. It is an intriguing mystery, as the reason for its occurrence does not have a definitive answer. Why does the wave suddenly turn into a particle? The most widely accepted interpretation of this question is the Copenhagen interpretation. It is a set of views on quantum mechanics attributed to its creators Niels Bohr and Werner Heisenberg and contains many factors. However, this article will be discussing the interpretation's main component of measurement: the act of "observation" is what causes the wave function to collapse. (Ren, 2012)

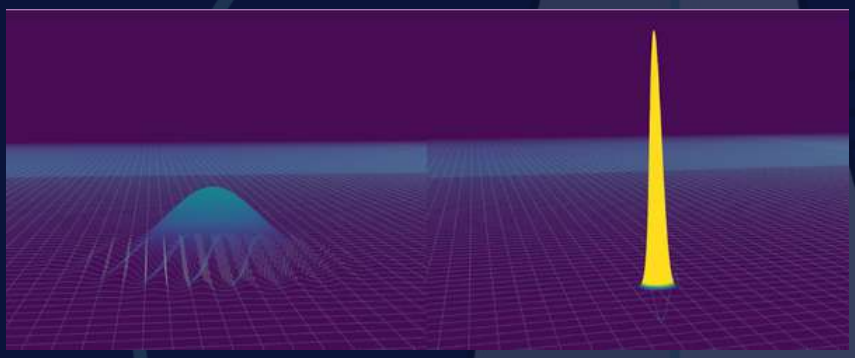

Fig 2.1 *The smooth wave of the Schrödinger equation vs the point-like particle detection. (Veritasium, 2020)*

However, this interpretation is flawed, as the term "measurement" is vague at best. Even Albert Einstein thought it was illogical, asking "does that mean the Moon is not there when I am not looking at it?" (Schreiber, 2020) The thought of items and objects existing in a foggy state of limbo when unobserved is mind-boggling and completely changes the concrete, deterministic nature of physics itself.

III. SCHRÖDINGER'S CAT

A famous thought experiment to visualize the Copenhagen interpretation is Schrödinger's Cat. It was proposed in 1935 by the Austrian physicist Erwin Schrödinger (The Nobel Prize in Physics 1933, 2022) in order to illustrate this absurd paradox and highlights the implication that allowing the interpretation to be used on a microscopic, quantum level would mean that it reflects on larger scale macroscopic objects too.

Schrödinger's Cat questions what would happen if a cat were to be trapped within a box with a machine containing a radioactive nucleus with a 50% chance of decaying, a Geiger counter and a lethal poison. If the nucleus were to decay, the Geiger counter

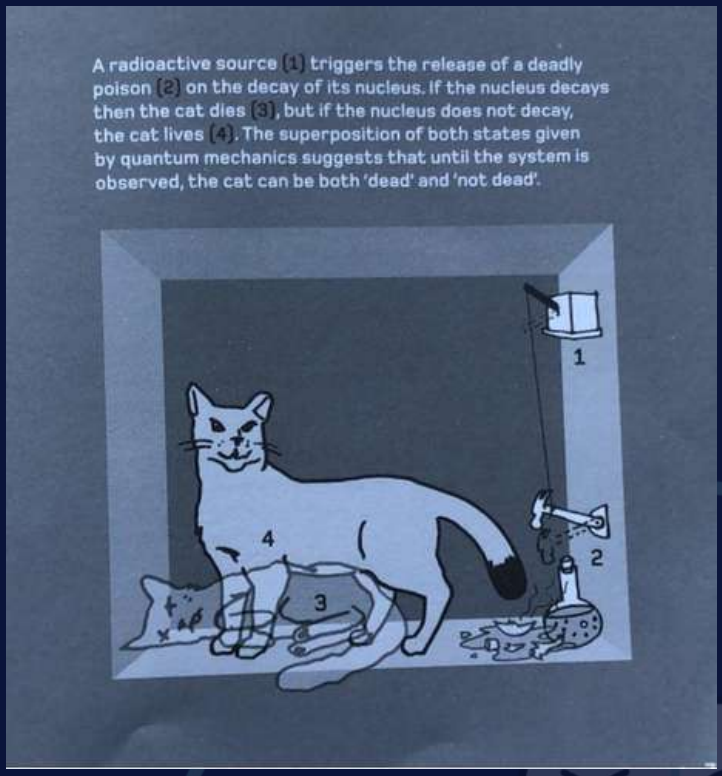

Fig 3.1 *Schrödinger's Cat (All hypothetical, no cats were harmed in the making of this theory)*

would pick up on the radiation and trigger a hammer mechanism, thus smashing the bottle of poison and killing the cat. Conversely, if the nucleus remained undecayed, the bottle would not be smashed and the cat would stay alive. So what would happen if this box was left undisturbed for an hour?

To a normal person, the answer would be blatantly obvious: the cat would be alive or dead, depending on whether the nucleus decays or not. However, according to quantum mechanics and the Copenhagen interpretation, the cat is both alive and dead at the same time - it is only when the box is opened that the observer can see a single conclusive state. It sounds nonsensical, which was exactly Schrödinger's point. In fact, it was so confusing to him that he rejected the theories of quantum mechanics he helped to create and instead turned to become a biologist. (TED-Ed, 2014)

However, many different alternatives to how the collapse of the wave function occurs do exist, one of which is the many-worlds interpretation. (Howgego, 2019) This is explained further in Tammi Ip's article, which I highly recommend that you read if you want to understand more about entanglement and the Heisenberg Uncertainty Principle, or just quantum theory as a whole.

Needless to say, quantum mechanics is a very complicated subject - one which physicists today still can't fully comprehend. For something that's quite literally everywhere yet naked to the human eye, the secrets of the quantum realm have without a doubt become one of the largest and most important mysteries. Who knows what we'll find in this new frontier of scientific exploration? Maybe the wave function and the zombified cat could be the key to unlocking the secrets of our universe.

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Parallel Universes and the Many-Worlds Interpretation

Tammi Ip 11R

Parallel universes are undoubtedly a well-versed trope in science fiction. It's easy to entertain such an idea of a different version of yourself living your ideal life. At the same time, it's just as easy to dismiss such a sentiment as a fantasy. However, there is some supporting and quite surprising science behind this nonsensical thought.

The basics of this topic are outlined in Hannah Lee's article on Schrödinger's Cat, explaining the two key concepts of quantum mechanics: superposition and measurement. In this article, we will discuss further in-depth, focusing on Heisenberg's Uncertainty Principle and the Many-Worlds Interpretation.

HEISENBERG'S UNCERTAINTY PRINCIPLE

Heisenberg's Uncertainty Principle is a statement articulated by German physicist Werner Heisenberg that states: **it is impossible to measure both the position and momentum of a particle at the same time with exact precision** ("uncertainty principle | Definition & Equation | Britannica," n.d.). Now, this might appear odd as it does not seem very difficult to measure the momentum and position of, for example, a ball being thrown.But, for a subatomic particle, any attempt to measure its position and momentum becomes meaningless as the uncertainty of these measurements become more significant. This uncertainty is not a fault of the measuring equipment or any human error; rather, it is linked with the wave-particle duality of objects.

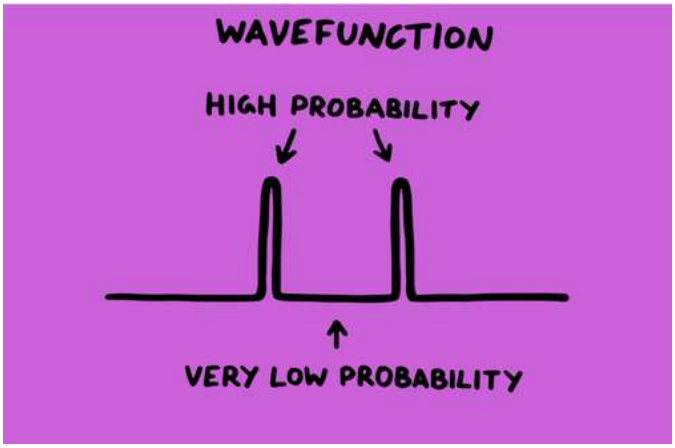

Fig 1.2 *Wave function describing superposition. (DoS, 2019)*

Electrons can exhibit diffraction patterns, so they may travel space as a wave, possessing wave-like properties, such as having a wavelength. It was proposed by French physicist Prince Louis-Victor de Broglie in 1923, that all particles may show wave-like properties. He took the concepts of relativity and quantum mechanics and merged them to create the equation - de Broglie wavelength, defining the wavelength of a moving particle:

$$\lambda = h/p$$

h is Planck's constant and this is an extremely small number (6.63 × 10-34 m2 kg / s). The letter p stands for momentum.

Since all macroscopic objects have wavelengths, why aren't we able to see them? Well, we certainly saw it with the double-slit experiment. To rephrase the question, we have to ask why we are not able to see wavelengths of macroscopic objects. The explanation is that the wavelength is too infinitesimally small to be seen. As an example, the wavelength of a 3 kg bowling ball moving at 10 m/s is 2 x 10-35m. For comparison, this is millions of times smaller than a proton or a neutron. To produce an interference pattern, the object has to interact with something of the size of its wavelength (The Wave Nature of Matter | Physics, n.d.).

Subatomic particles, on the other hand, have large wavelengths. They can be detected and their momentum can be measured. Yet, we cannot see these subatomic particles. To see something, light has to reflect off of its surface, entering our eyes where it is processed by our brains. Subatomic particles are so tiny, light simply passes straight through them. We can try to work around the problem by "compressing" the electromagnetic wave - creating waves with shorter wavelengths and higher energy. When we fire these high-frequency waves at the particles to see them, it fundamentally changes them (Kursgesagt - In a Nutshell, 2018).

Thus, we have no way of knowing the exact position of what we can't see. It creates a paradox where if the momentum of an object is measured at high precision, its position becomes less precise and vice versa! In the Copenhagen Interpretation, this observer effect is stated to cause the observed object to be in the state of either a wave or a particle but not both. A different interpretation argues that the world splits into parallel universes. It splits every time a measurement is made in respective universes, one where the object behaves like a particle and one where it behaves like a wave.

QUANTUM ENTANGLEMENT

But before we can understand the parallel universes interpretation, we must first explore Quantum Entanglement. Let's say you have two marbles, one red and one blue. They are hidden under two paper cups. You are told to guess which cup has which marble. The marbles are in a state of superposition - either cup can have either colour. When we open one cup, we can immediately know the colour of the marble in the other cup too. These two systems are somehow intertwined together. This classical analogy is the concept which quantum entanglement is based on.

Now, let's apply this concept to an electron. We would normally think of an electron as a minuscule negatively charged particle orbiting the nucleus of an atom. Though now we've gained the understanding that electrons can behave as a wave, of which the position we

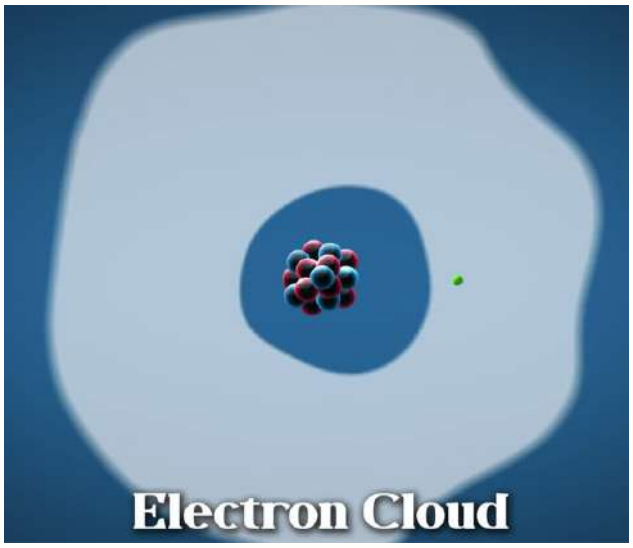

Fig 2.1 *Electron cloud around an atom. (Science ABC, 2020)*

can't determine accurately due to Heisenberg's Uncertainty Principle, a more correct interpretation proposed by Erwin Schrödinger would be: electrons are in a state of superposition. We know it exists somewhere around the nucleus based on probabilities (Williams, 2016).

The probabilities are visualised in orbitals or electron clouds shown on the left. There's a higher probability for electrons to be where the cloud is denser. Just like how an object in a 3D space might be represented by the quantities x, y and z, an electron has a set of quantities that define them known as quantum numbers.

Similar to the cups and the marble, it is possible for the properties of these two electrons to get "entangled". Let's take ms, the **electron spin quantum number.** The textbook definition of the electron spin of a quantum number is the intrinsic value of the angular momentum of a fundamental particle (Science ABC, 2020).

The probabilities are visualised in orbitals or electron clouds shown on the left. There's a higher probability for electrons to be where the cloud is denser. Just like how an object in a 3D space might be represented by the quantities x, y and z, an electron has a set of quantities that define them known as quantum numbers.

Einstein originally found this phenomenon uncomfortable as this implied faster than light communication, defying the laws of relativity. In actuality, when the two particles interact, they become defined by a singular wave function, only leaving measurement to collapse the wave function and give us the internal state of both electrons (Veritasium, 2020).

In this way, the mystery of measurement can be solved - there is no collapse of the wave function!

MANY WORLDS INTERPRETATION

Well, this is where the many-worlds interpretation comes into play.

Using Schrödinger's cat thought experiment, we can say that the radioactive nucleus is in a superposition state of decayed and not decayed. It gets entangled with the Geiger-Muller tube and counter and then the cat. So, the cat is both dead and alive. Right now, by the Copenhagen interpretation, when the box is opened, the cat chooses one of two states due to the wave function collapsing.

On the other hand, in the many-worlds interpretation, the observer themselves gets entangled with the quantum system (Veritasium, 2020).

We split into parallel universes, each version of the observer is entangled with the outcome cat being dead and alive respectively. There are essentially two timelines,

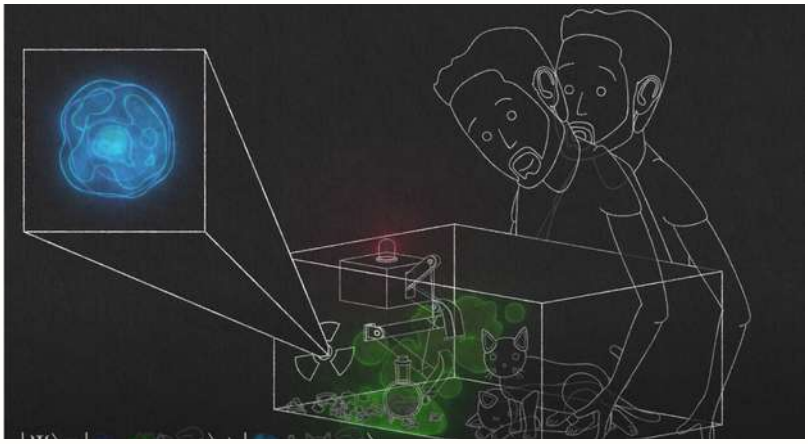

Fig 3.1 *Schrödinger's cat explained using many worlds interpretations. (Veritasium, 2020)*

one where the cat is dead and another where the cat is alive. The observers are now two vitally different people progressing at the same space and time, in alternative timelines.

The many-worlds interpretation states that there is no wave function collapse and all possible outcomes of when a quantum system is measured are registered in some alternate reality. Every outcome is bound to happen, only in different universes.

In context, a split in the timeline can be caused every time a radioactive atom's state of superposition is determined, to be decayed and not decayed. Even radioactive atoms from our body, like C14, can interact with particles in the environment, become entangled and cause a timeline split. Whether this happens infinitely often is still a mystery yet to be solved (Veritasium, 2020).

A multiverse, now explained with physics, the notion created by science fiction that says a version of ourselves could be doing anything and everything could possibly be true. But instead of entertaining the grandeur of a universe we have still yet to understand, we can always strive to be the best versions of ourselves in our own, one and only timeline.

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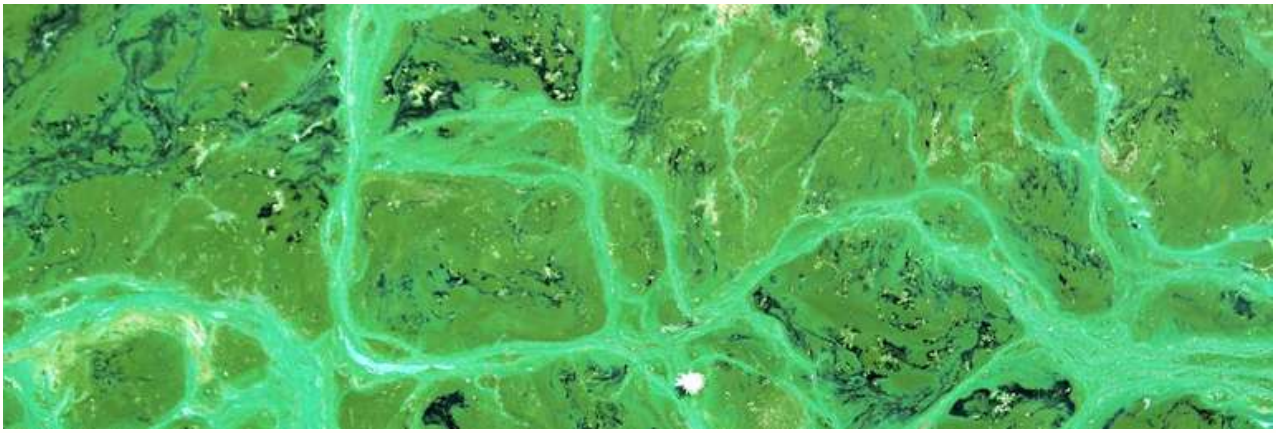
Cyanobacteria: Tiny Organisms That Helped Shape Life As How We Know Today

Charmaine Hui 12E

Looking at these tiny rod-like strands, you probably wouldn't have guessed that they originated from 3.5 billion years ago. These little organisms are called cyanobacteria, also more commonly known as blue-green algae. They don't look like much, but they have changed the course of life on Earth by diversifying the varieties of organisms and introducing photosynthesis to them.

WHAT ARE THEY?

Cyanobacteria are gram-negative bacteria that are able to photosynthesize. They can exist in many different forms, from unicellular to colonial to filamentous. They are found naturally in all kinds of water, and are found to be able to survive extreme temperatures and salinities. Basically, they are all around us! From the icy waters in the Arctic to brackish swamps to freshwater lakes, cyanobacteria are present in all of them. This is due to the fact that they are autotrophic and can photosynthesize their own food to use for respiration and their ability to rapidly grow when put in the right conditions. Unlike other heterotrophic bacteria, cyanobacteria have flattened membrane sacs in them (think of them as internal organs) that contain chlorophyll called thylakoids. Photosynthesis happens in those thylakoids, using chlorophyll to capture solar energy and converting it into chemical energy in the presence of carbon dioxide. Nitrogen-fixation can also happen in filamentous cyanobacteria when it encounters nitrogen starvation. Some cells in the filamentous cyanobacteria can be differentiated to form heterocysts, which are able to "fix" aerobic nitrogen into nitrogen compounds that can be used by the cyanobacteria for growth. Interesting, right?



Cyanobacteria are also called “blue-green algae” because their bacterial blooms often cause the water to turn blue, green or brown. When the water is rich (aka polluted with organic industrial waste) with phosphorus or nitrogen compounds and there is adequate sunlight, these cyanobacteria will rapidly multiply and create bacterial blooms that will release concentrated cyanotoxins. When these cyanotoxins reach certain concentrations or become airborne, they become harmful to humans. There are different types of cyanotoxins, including microcystin (the most common and toxic cyanotoxin-it is a potent liver toxin and possible carcinogen), saxitoxin (a potent neurotoxin that is responsible for the illness known as paralytic shellfish poisoning), and lyngbyatoxin-a (a potent blister agent and carcinogen). Gastrointestinal effects from the consumption of cyanotoxins include nausea, vomiting, and diarrhea. Other effects include: conjunctivitis, rhinitis, earache, sore throat, swollen lips, bronchospasm, pneumonia, dermatitis, perioral blisters, lacrimation, swelling of the eye, and photophobia. (sounding like those drug commercials lol teehee)(probably would have to cut it down...)

HOW DID THEY HELP SHAPE LIFE AS WE KNOW IT TODAY?

Early Earth was a place devoid of oxygen. This made primitive life have only limited options for growth. They were all prokaryotes that used anaerobic respiration to produce energy for growth, limited to a small size due to the inefficiency of anaerobic respiration. About 2.4 billion years ago, cyanobacteria appeared and started to produce oxygen. They are directly responsible for the rise of atmospheric oxygen levels, which led to the Great Oxidation Event approximately 2.4-2.0 billion years ago.

The Great Oxidation Event, as its name suggests, was the great change in the course of life of many animals facilitated by the abundance of atmospheric oxygen. As oxygen was highly toxic to many anaerobic organisms that appeared at that time, most of them died out. The rest of them retreated to places where oxygen couldn’t reach them, like volcanic geysers, and became extremophiles. However, the Great Oxidation Event was also responsible for the emergence of more diverse organisms due to aerobic respiration being a much more efficient way of producing energy. It also made the Earth suitable for animals, like us, to live.

Other than producing oxygen directly, cyanobacteria also facilitated the evolution of plants. The endosymbiosis-- the relationship between two organisms where one lives inside the other- between cyanobacteria and another prokaryote explains the formation of chloroplasts in plants. In other words, cyanobacteria introduced the mechanism of photosynthesis to other organisms, which lets them create more oxygen into the atmosphere.

CONCLUSION

Cyanobacteria are absolutely essential in the evolution of life as we know today. They are pivotal in changing the Earth's atmosphere from being carbon-dioxide-rich to being oxygen-rich. They also help the environment by being able to fix atmospheric nitrogen to create nutrients using heterocysts, detoxifying heavy metals in the water, and producing bioactive compounds like vitamins and hormones.

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WHY DO SO MANY WOMEN GET BREAST CANCER?

Charlene Cheung 12N

The most common life-threatening cancers we hear of include lung cancer and leukaemia. (Blagosklonny, 2004) However, in 2020, breast cancer has overtaken lung cancer as the most prevalent disease worldwide. Globally, 2.3 million women and 2650 men were diagnosed with breast cancer. The underlying reason why most patients are women will be revealed in this article. (Blagosklonny, 2020)

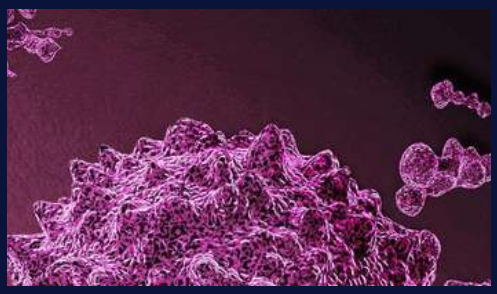

Fig 1: A Breast Cancer Cell

WHAT IS BREAST CANCER?

Breast cancer develops when cells in the breast divide uncontrollably, leading to tumour growth. It is considered malignant (cancerous cell) when cells do not behave normally. ("Breast Cancer Statistics And Resources", 2020) Invasive breast cancer then occurs when the cancer cells continue to divide. Breast cancer arises in several parts of the breast. Proliferation-wise, breast cancer can spread through the body by invading the lymphatic system and blood, it is called metastasis. The breast cancer cells can escape and enter the surrounding lymph tubes, or spread throughout the body via lymph nodes, which are the most common sites where breast cancer spreads. Breast cancer cells can also enter the blood vessels to travel around the body.

SYMPTOMS

Warning signs appear in the early stage of breast cancer that draws medical attention.

1. A new lump shows up within the breast or armpit
2. Swelling and solidifying of a portion of the breast
3. Dimpling or itchiness of the skin of the breast
4. In the nipple region of the breast, there is redness or cracking skin.
5. Change in breast size
6. Any portion of the breast may well be painful. ("Breast cancer - Symptoms and causes", 2020)

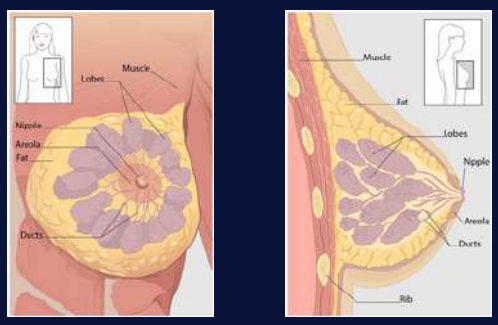

Fig 2: Breast Structure

Fig 3: Breast Cancer Symptoms

COMMON RISK FACTORS THAT MAY CAUSE BREAST CANCER

AGE:

Normally, women aged 50 years old or above are more prone to breast cancer. A 20-year-old female has a 0.06% risk of developing in the following decade. This proportion rises to 3.84% by the age of 70, because we may not be able to reproduce as many cells as before. With fewer effective cells, the rate of hormone receptors increases, so do the probability of encountering genetic mutation upon ageing. ("Breast cancer", 2021)

GENETIC MUTATION:

Inheritance of a mutation in BRCA1 and BRCA2 genes would increase the chance of suffering from breast cancer. Usually, damaged DNA is repaired by the protein made by BRCA1 and BRCA2 genes. However, uncontrolled cell growth would result if these genes are mutated. A woman having a BRCA1 or BRCA2 gene mutation would have a 70% chance of developing breast cancer at the age of 80. ("Breast Cancer Risk Factors You Can't Change", 2022) Carrying a copy of mutated genes from parents and other genes such as ATM and TP53 also contribute to breast cancer development. ("What Are the Risk Factors for Breast Cancer?", 2019)

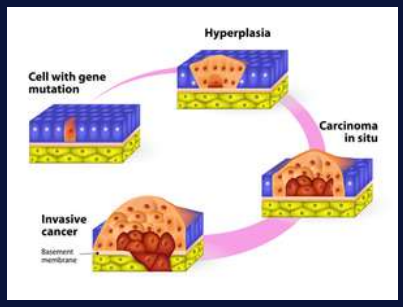

Fig. 4: Genetic Mutation

EXPOSURE TO OESTROGEN:

Higher levels of exposure to oestrogen, caused by early menstruation before the age of 12 or old age pregnancy would potentially activate breast tissue to accelerate cell division and replication, which damage DNA and lead to mutations. (Brinton, 1996)

COMPARISON BETWEEN THE RATE OF MALES AND FEMALES DEVELOPING BREAST CANCER

Male breast cancer is a relatively uncommon medical illness, accounting for less than 1% among all other cases. ("Clinicopathological study of male breast carcinoma", 2020) The American Cancer Society stated that roughly 2,600 new instances of breast cancer in males are found each year, and approximately 440 men die from the disease compared to 40000 women yearly. ("Why Is Breast Cancer More Common in Females than Males?", 2019 A man usually develops breast cancer between 60 and 70 years old.

WHY IS IT MORE COMMON IN WOMEN?

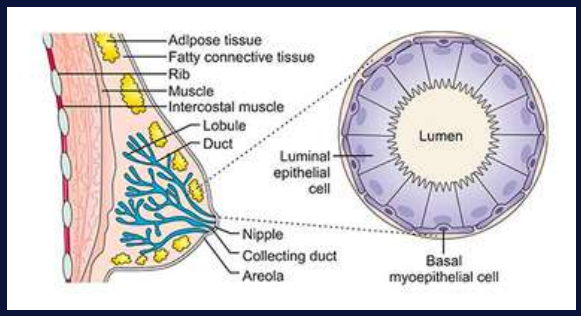

Fig. 5: Breast Structure

Breast development makes females more susceptible to breast cancer. Breast cancer usually takes place in the milk ducts and lobules. ("Why Is Breast Cancer More Common in Females than Males?",2020) During puberty, both male and female breast tissues consist of a few ducts beneath the nipple and areola. ("Male vs. female breast cancer", 2018) For females, elevated amounts of specific hormones will be generated, causing these ducts to expand and lobules to develop. Whereas for men, low amounts of these hormones explain why breast tissue in men does not expand that much. Male breasts contain ducts, but just a few lobules and are mostly made up of fat tissue. High levels of oestrogen production in women also contribute to the increased risk. Breast cells divide and expand in response to the hormone oestrogen that females produce in greater amounts than males. ("Male vs. female breast cancer", 2018) Additionally, female breast cells are extremely active and sensitive to oestrogen, whereas breast cells in men are inert and not associated with high oestrogen levels. (Mankoff, 2005)

Fig. 6: Surgery

Fig. 7: Radiotherapy

TREATMENT

SURGERY:

Surgery is the most suitable treatment for stage 1 breast cancer. In particular, breast-conserving surgery is available if the tumour and a margin of surrounding tissues can be removed while maintaining the look with enough tissue following surgery. A mastectomy is suggested under the following circumstances: there is cancer in more than one location of the breast or in the tissue removed, also when no tumour in the breast but a small quantity of cancer in the lymph nodes. (Hernanz, 2004)

RADIOTHERAPY

For stage 1 patients, radiotherapy is recommended after breast-conserving surgery but not a mastectomy. The lymph nodes beneath the arm and around the collarbone, as well as the whole breast, are tackled. An additional dosage of radiation, known as a boost, may be delivered to the region where the tumour was removed. (Yarnold, 2006)

BREAST CANCER TREATMENT IMPACTS ON WOMEN - PHYSICALLY & PSYCHOLOGICALLY

Treatments of breast cancer have extensive impacts on both women's body image and their well-being. The consequences on body image are alterations in sexual function, low self-esteem, and relationship issues. Body image involves a sense of purpose and completeness for women rather than merely physical appearance. Women who regard body image as a key component of self-worth and beauty are more vulnerable to negative psychosocial adjustment after breast cancer treatment.

CONCLUSION

Breast cancer is a common disease in our society that you and I should pay heed to, but don't panic, as long as we maintain a healthy lifestyle, exercise regularly and consume nutritious food, these diseases will be kept away from us. So what are you waiting for? Come and set up a healthy lifestyle now!

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How Does Alcohol and Marijuana Use Influence Teenagers' Brain Development?

Hailey Lau 11N

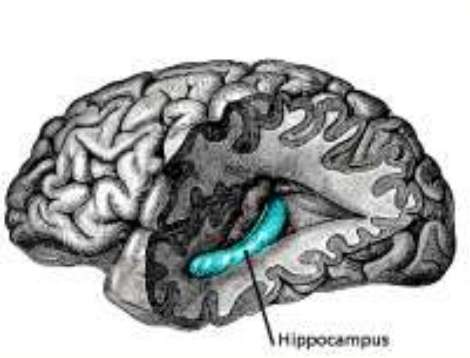
Alcohol. Drugs. Marijuana. These words are most commonly heard amongst the young community. But are these substances as detrimental as some may portray them? There is no doubt that they damage the brain development of teenagers, but to what extent?

This article will focus on the impacts of alcohol and Marijuana on the brain development of adolescents, those within the age range 10-24. As expected, alcohol is one of the most commonly used substances within the teenage community, accounting for 27% of 15-19-year-olds reporting alcohol use in the past month. Marijuana follows in the list of most used substances during the period of adolescence, with the overall rates of use soaring incredibly each year.

ALCOHOL IMPACTS

HIPPOCAMPUS SHRINKAGE AND BLACKOUTS

The hippocampus is a seahorse-shaped region deep inside the brain. It is responsible for learning and memory. Under the influence of heavy alcohol, a smaller hippocampus may form, meaning that they may not be as cognitively competent as their peers.



"The more people drink, the smaller their hippocampus," said Miss Anya Topiwala, a psychiatry professor at the University of Oxford. She stated that consuming one more alcoholic drink per week could lead to a 0.01% decrease in the size of the hippocampus.

Thomas P. Beresford, a professor of psychiatry at the University of Colorado Health Sciences Center conducted a study that demonstrated the reduction in total hippocampus volume among alcoholics. MRI scans were used to capture images of the brains of those who were allegedly 'alcoholic' and measured the size of their hippocampus. After collecting his results, he confidently stated they were "much smaller than the hippocampus in the group of people who did not drink alcohol heavily. This means that alcohol appears to injure the hippocampus by itself. That is, it may harm the hippocampus in a way that other things do not."

Moreover, many alcoholics have experienced an occurrence called the “blackout”. It involves a sudden memory disruption, causing them to forget about details they can usually recite fluently. How does that happen? When the alcohol arrives at the hippocampus, it significantly reduces the electrical activity of neurons by binding to specialized receptors, which are deeply embedded in the neuronal membrane. The reduction of firing impulse in the hippocampus disrupts the creation of short-term memories, and more severely, causes “blackouts” as society knows them.

Alcohol results in memory impairment in the long term. From the scientific perspective, alcohol affects the Gamma-Aminobutyric acid (also known as the GABA) and the N-methyl-D-aspartate (NMDA) neurotransmissions, this negatively impacts the long-term potentiation. Long-term potentiation (also known as the LTP) is a process that involves a consistent strengthening of the synapse, which causes an increase in signal transmission between neurons. As a result, this decelerates the ability to learn and retain memories in the hippocampus.

DISRUPTED ATTENTION

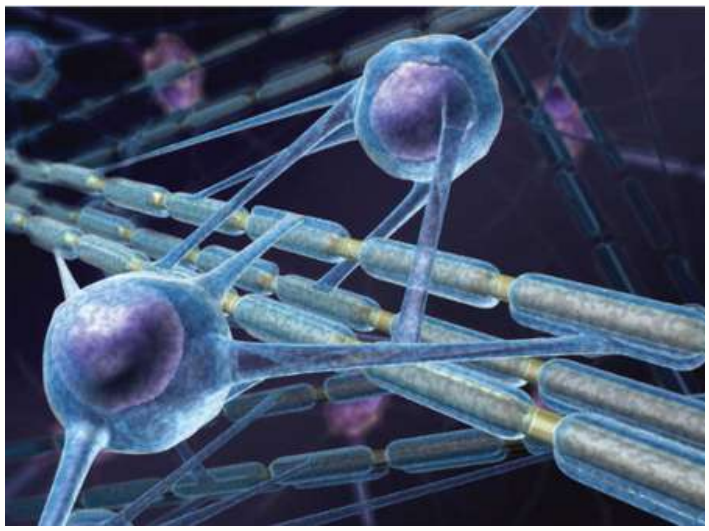
On the other hand, alcohol intoxication also leads to disrupted attention. The hormone that associates with attention is called Norepinephrine, and it is released by the brain when the focus is needed by the person. The Locus Coeruleus secretes Norepinephrine, and it attaches to the Bergmann glia, which accounts for the production of neurons in the cerebral cortex. This attachment causes elevated calcium levels in the cells. However, alcohol inhibits the calcium activation in this area, eventually leading to difficulty in paying attention.

IQ DECREASE

The consumption of alcohol is associated with an IQ decrease as well. Sara Sjölund, a doctoral student at the Karolinska Institutet in Stockholm stated, "We found that lower results on IQ tests in Swedish adolescent men are associated with a higher consumption of alcohol, measured in both terms of total intake and binge drinking," Furthermore, women who drink while pregnant put their fetal at risk of Autism. Children born with Foetal Alcohol Syndrome are found to have an intelligence below average.

Several researchers immediately pointed to thiamine (Vitamin B1) deficiency as the cause for IQ reduction. Many of those who consume alcohol regularly, or suffer from alcohol use disorder, end up having a thiamine deficiency. But why? Heavy alcohol consumption causes inflammation of the stomach lining and the intestines, which decreases the ability of their body to absorb nutrients, hence absorbing less thiamine.

WHITE MATTER BRAIN DAMAGE



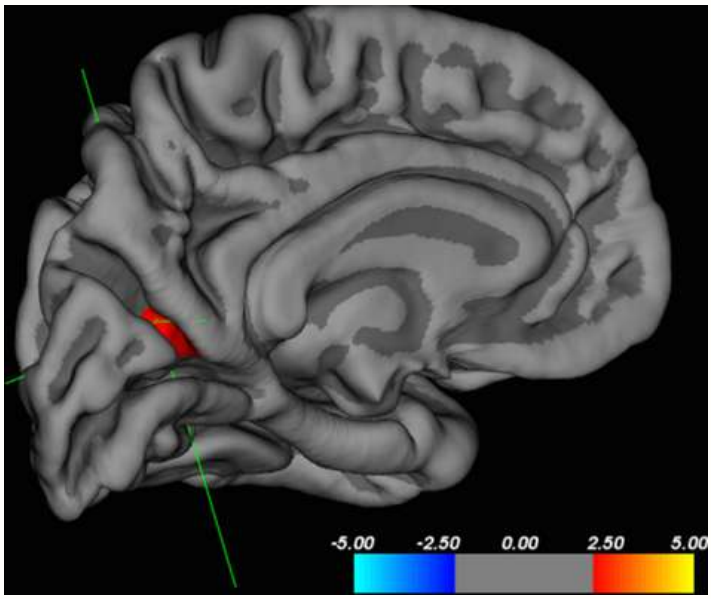
White matter plays a dominant role in delivering messages to the brain and between the brain and spinal cord. They are tissues in the brain composed of nerve fibres. These axons connect nerve cells and are covered by myelin.

Heavy drinking may be the cause of white matter being damaged in the frontal lobe. A research was conducted where MRI scans were used to compare the brain of 20 light drinkers and 31 abstinent drinkers."First, recovered alcoholics showed reductions in white matter pathways across the entire brain as compared to healthy light drinkers. This means that the pathways that allow the different parts of their brains to communicate efficiently and effectively are disrupted by alcoholism," Catherine Fortier declared, a neuropsychologist at the VA Boston Healthcare System and an assistant professor at Harvard Medical School.

On top of that, drinking alcohol can also cause White Matter Hyperintensities, which are lesions in the brain that are seen as an area with increased brightness. The presence of white matter hyperintensities could be dangerous, as it has been correlated with a higher risk of stroke, leading to vascular dementia. Essentially, as people consume alcohol, it increases their blood pressure, causing an accumulation of cholesterol, highering the risk for White Matter Hyperintensities.

ACCELERATE DECREASE IN FRONTAL CORTICAL THICKNESS

Most studies indicate that general intelligence is largely associated with their cortical thickness. Cathrine Fortier, an assistant professor of Psychology in Psychiatry at Harvard, and her colleagues compared MRI scans from 65 participants. Participants are separated into 2 groups: 31 abstinent alcoholic participants and 34 non-alcoholic control participants.



The scans were used to generate a cortical-surface model, and cortical thickness was then determined based on the distance between the grey matter boundary and the outer cortical surface. Through this investigation, it was discovered that the outermost layer of cortex across the brain is reduced, only in the group of recovered alcoholics. She later added, "Severe reductions in frontal brain regions can result in a dramatic change to personality and behavior, taking the form of impulsivity, difficulty with self-monitoring, planning, reasoning, poor attention span, inability to alter behavior, a lack of awareness of inappropriate behavior, mood changes, even aggression."

INCREASED BLOOD FLOW IN THE RIGHT PREFRONTAL CORTEX

As alcohol is consumed, blood flow in the right prefrontal cortex in a dose-dependent manner is increased. Cerebral blood flow is tightly controlled to meet the metabolic demands of the brain. The Cerebral blood flow is the blood supply to the brain in a given period of time. When there is too much blood flow to the brain, intracranial pressure can increase greatly. Therefore, running the risk of compressing and damaging delicate brain tissues.

MARIJUANA IMPACTS

REDUCE PSYCHOMOTOR SPEED

In simpler words, psychomotor speed refers to the speed of thinking. A study revealed that Marijuana used in middle adolescence affects psychomotor development. The substance that affects psychomotor function is Δ9-tetrahydrocannabinol. Δ9-tetrahydrocannabinol is a component of Cannabis, and can acutely introduce psychotic symptoms, such as decreasing psychomotor speed.

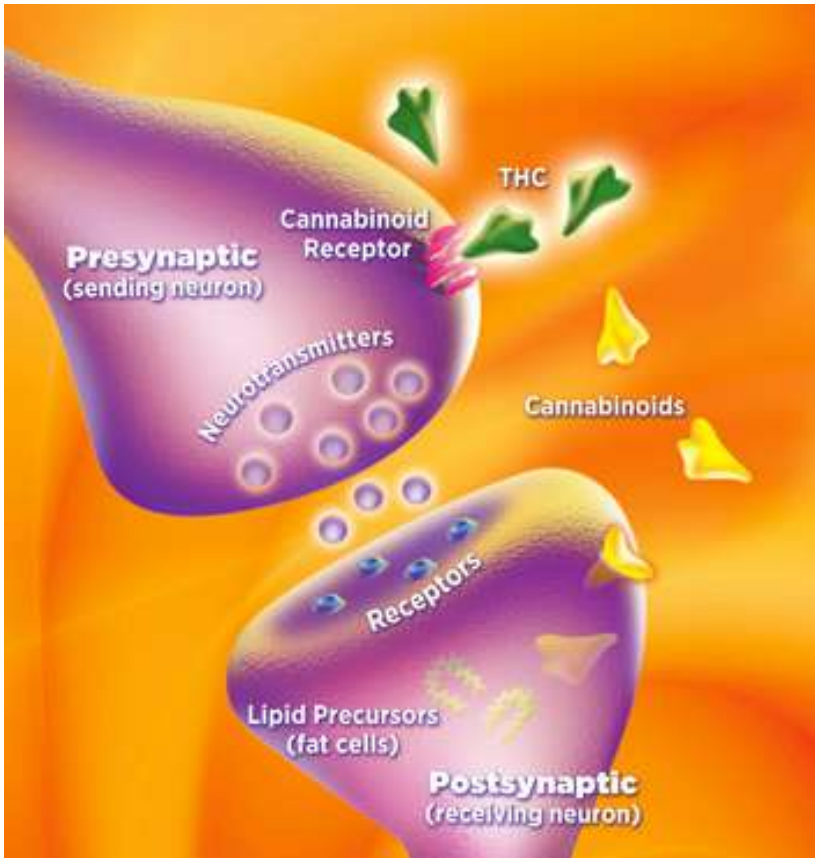
A present study investigated the psychomotor function in chronic daily cannabis smokers during 3 weeks of sustained cannabis abstinence. The Psychomotor speed was assessed with critical tracking and divided attention tasks; where the results were compared in the end. The results showed that when you compare these cannabis smokers with controls, they display significantly larger tracking errors.

In summary, psychomotor functions of these chronic Marijuana smokers improved during 3 weeks of monitored abstinence but didn't return to initial normals, compared to the control group.

ABNORMALITIES IN THE NUCLEUS ACCUMBENS AND THE AMYGDALA

The Nucleus accumbens and the amygdala are the main components of the limbic system. In the nucleus accumbens, the Tetrahydrocannabinol binds to CB1 cannabinoids neural receptors and stimulates dopamine transmission from the ventral tegmental area to the nucleus accumbens. The nucleus accumbens is a region that functions with reward-driven behavior. It will then be damaged as THC arrives and binds to it.

The Amygdala is the brain region that is responsible for emotional processes. Same as the Nucleus accumbens, as the amygdala is given a higher density of THC, it will cause hypersensitivity to signals of threat. Hypersensitivity is automatic reactions that are produced by the immune system.



Moreover, as THC binds to cannabinoid receptors in the amygdala, it creates "signals" that induce an emotional response. As the amygdala is responsible for the fight-or-flight response, it will trigger acute stress and frightened response as the body prepares for the 'fight-or-flight'. Chronic use of Marijuana can lead to downregulation of it's cannabinoid receptors. Eye-tracking tests showed that overdose of THC can cause a myriad of anxiety, in a similar manner as those with diagnosed anxiety disorders. As a result, chronic use of Marijuana can easily escalate into a full-blown panic attack and paranoia.

DECREASE GREY MATTER

Brain imaging studies have been conducted by the NIDA. It has shown that chronic users of Marijuana have less grey matter than non-users in the orbitofrontal cortex. This specific region contributes to impulse control, making decisions and learning. Dr Francesca Fillbey from the University of Texas led a study regarding the matter. They recruited 110 participants, 48 Marijuana users and 62 nonusers. MRI scans were conducted on all of them. Regular users of Marijuana were shown to have less grey matter, which translates to lower neuron density, in 2 regions of the orbitofrontal cortex. Dr Filbey later explained "having smaller grey matter volumes in the OFC will make it a challenge for them to change behaviours that they learnt earlier. For example, if someone has learned that Marijuna makes them feel satisfied, it will be difficult for them to unlearn this behaviour, leading to more negative consequences."

IS ALCOHOL OR MARIJUANA MORE DAMAGING?

"The difference between alcohol and cannabis is pretty dramatic," stated Kent Hutchison, a professor of Psychology and Neuroscience at the University of Colorado Boulder. He later expressed that alcohol actually takes a greater toll on the brain of adolescents than Marijuana does. It was also explained that there are more impacts of Alcohol, which could include the effects on the hippocampus, white and grey matter decrease,etc. There are overall more impacts of alcohol on the brain, than Marijuana.

CONCLUSION

In conclusion, both Alcohol and Marijuana have negative impacts on the brain developement of adolescents. Alcohol causes the hippocampus to shrink, disrupt attention, IQ reduction, white matter damage, accelerated decrease in frontal cortical thickness, and increase blood flow to the right prefrontal cortex. While Marijuana reduces psychomotor speed, causes abnormalities in the nucleus accumbens and amygdala, as well as diminishes grey matter in the brain. These effects are even more damaging to the adolescent brain as they are still in the process of development. There are still major changes in the brain structure, hence any damage will be particularly dangerous.

With all these adverse effects of Alcohol and Marijuana, isn't it better to quit these habits altogether?

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How Are Different Forms of Medical Drugs Absorbed into the Body?

Tsz Yu Chan 11E

INTRODUCTION

A drug, in terms of pharmacology is a substance that is administered to an organism that creates a biological effect by releasing ingredients (Definition of drug | Dictionary.com, 2022). Although drugs come in all different shapes and forms, the reasoning behind them isn't quite well known. This article will explore such differences and their purpose.

PILLS

Firstly we will be looking at pills and all their formats. Pill is the general term for any medication that is, rounded and circular, which is ingested through the mouth and absorbed through the digestive system.

A capsule is another form of a pill. It holds powder or liquid inside them that contains the active ingredient. They are contained in a hard case that is often made out of gelatin, as well as other substances to adjust its solubility to manipulate where the case will dissolve in the body. This makes a 2 piece encasement that comes together to contain the substances and will release the ingredients when the case dissolves. The case in general allows for quick dissolving, allowing ingredients to swiftly get into the bloodstream.

Another format of pills that is similar to capsules is soft gels . Here, The case is one piece and has glycerin mixed with gelatin making it less rigid and smoother. They mainly contain based-oil or oil suspended ingredients.

Another type of pill is tablets, which are hard due to the fact that they are made by compressing the powdered ingredients into the shape required, which dissolves in the digestive tract. Tablets are often cheaper than capsules as they don't have a casing but are sometimes coated in substances that decrease their solubility so it doesn't dissolve in the stomach instantly, instead they take time to dissolve in the stomach so when the stomach releases the chyme into the small intestine the outer layer of the tablets are fully dissolved making it easy for the small intestines to absorb the medicine.

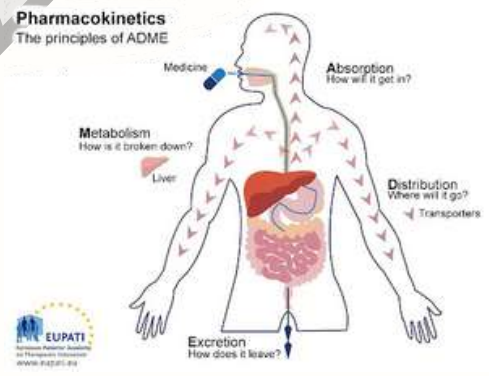

Fig 1: *ADME (EUPATI, 2021)*

There is also a form of chewable tablet . These tablets are generally larger as they are less concentrated than regular tablets and have ingredients like sugar. Chewable tablets are mainly for children or the elderly who have difficulty swallowing.

SKIN BASED MEDECINE

There is quite a lot of confusion between creams and ointments as they are both semi-solid emulsions that suspend their active ingredients in the emulsion and are both applied and absorbed by the skin. The difference between them is that creams have a high water to oil ratio, while ointments are mainly made with oil and a very small amount of water.

The other skin-based medicine that will be talked about is lotion, a medicine in which the active ingredient and other ingredients are suspended in water, making it a water-based medicine.

The factor that relates all three medicines besides suspending ingredients is that they are all regional instead of systematic, which means that they only affect the region that it is applied instead of the entire body (Overview of Anatomy and Physiology | Anatomy and Physiology).

POWDERED MEDECINE

This is the medicine that takes the form of powder. We have already discussed that this is used to make tablets and put into capsules but there are also other ways to administer this medicine. Powder can be reconstituted with a liquid and then drunk or injected. The process of reconstituting medicine is very precise and needs to be done by specialists or is done on an industrial scale with pharmaceutical companies. The powder can be inhaled, such as in a dry powder inhaler for asthma. In asthma medications, the powder is kept under high pressure with gas, then released at high pressure so the powder can travel to the lungs where it is absorbed.

LIQUID MEDECINE

There are many types of liquid medicine for internal and external use. Some examples of internal-use are syrups and solutions. Some examples of external use medicine are sprays like nasal sprays and drops like eye drops. There are also different types of viscosity of liquid medicine, aqueous medicines being around as thick as water and viscous liquid medicine which have a thick consistency. Some ingredients are suspended in liquid so it is important to shake it to make sure the ingredients are evenly distributed throughout the solution.

TRANSDERMAL PATCH

These are patches that contain chemicals that are slowly released over a period of time. The effect they provide is systemic as the chemicals diffuse from the skin into the bloodstream. One example of this is a nicotine patch that helps people with a smoking addiction by slowly administering nicotine which reduces their reliance on cigarettes.

WHY IS UNDERSTANDING THE DIFFERENCE IMPORTANT?

It is useful to understand the difference between different forms of medicine as it helps you to be more informed when prescribed these medicines. And also when one has to purchase medicine, so they can accurately judge what they or someone else needs. Another reason would be safety, as it is important to understand that drugs administered incorrectly could be harmful or fatal. As an example, giving young children pills could be dangerous as they may experience difficulty swallowing them with water, which increases the likelihood the child would choke. That is why it is advised that young children take liquid medicine or chewables as it is generally safer.

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Immunotherapy: The Potential Cure for Cancer?

Quenie Lam 11E

INTRODUCTION

The human body is composed of trillions upon trillions of cells. Normally, human cells can divide and multiply in a controlled manner to produce new cells for growth and repair. But in some cases, abnormal or damaged cells can cause tumours, which are when cells congregate. They are classified as either benign, malignant, or precancerous.

A malignant tumour is cancerous, and it can spread to nearby glands, tissue, and other organs. These tumours may recur after treatment, making them life-threatening. On the other hand, benign tumours are not cancerous and seldom pose a threat. Precancerous tumours are precisely what their name suggests; they can grow into cancer if left untreated.

Cancer is one of the leading causes of death worldwide; the WHO reported 10 million cancer-related deaths in 2020. When dealing with such a deadly illness, you may wonder, why hasn't a cure been found yet?

Contrary to what some people might think, cancer is more of a family of diseases than a single classification. Around 100 different varieties of cancer have been identified. There are so many kinds of cancer that different approaches are needed to treat them. There's no universal "golden cure." It is also notoriously difficult to eradicate cancer cells because they can change and mutate over time. There must also be complete removal of the tumour because any cellular remnants could regenerate. Many scientists are researching and looking into potential cures, and immunotherapy seems to show much promise at the moment.

INTRODUCING CANCER IMMUNOTHERAPY

Cancer immunotherapy involves strengthening or modifying the body's immune system to attack cancer cells. There are many types of cancer immunotherapy, such as adoptive cell therapy, cancer vaccines, immunomodulators, oncolytic virus therapy, and targeted antibodies. This article will discuss various forms of one of the most promising forms of immunotherapy is adoptive cell transfer.

ADAPTIVE CELL TRANSFER

The four types of adoptive cell transfers are tumour-infiltrating lymphocytes (TIL), engineered T-cell receptors (TCR), chimeric antigen receptor T cells (CAR T cells), and chimeric antigen receptor natural killer cells (CAR NK cells).

The immune system is composed of T-cells derived from stem cells. These cells are involved in fighting infection and potentially even cancer. The body's naturally produced T-cells can target and destroy cancer cells precisely. However, it is imperative to activate the T-cells, then maintain them at an active state for a considerable time before they are effective.

Tumour-Infiltrating Therapy

TILs naturally occur within tumours and are collected during surgical resection or biopsy. After TILs are collected, they are grown in large quantities using the protein interleukin-2 [IL-2], facilitating rapid TIL growth ("TIL Therapy, Cellular Immunotherapy," 2021). They must select and multiply only the most potent and active cells for this procedure to work.

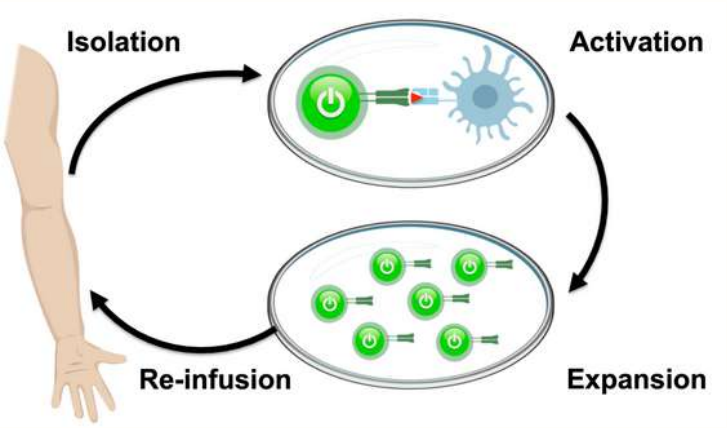

Fig 1: *How TIL treatment works*

Drip infusion is then administered to reintroduce them to the patient. Once TILs have been introduced into the body, they will attack the tumour cells as they travel around the body.

The potential side effects of the infusion include short-term fever, chills, and shortness of breath. Later symptoms include vitiligo, uveitis, and pancytopenia (low red, white blood cell, and platelet count). Additionally, the infusion of interleukin may cause some changes in blood pressure and heart rate.

Treatment of patients with metastatic melanoma, a type of skin cancer, using TIL has proven quite successful. The results of a follow-up study conducted in 2020 by Clayton Boldt with TIL-treated patients showed a response rate of 36% (Boldt, 2021). In addition, clinical trials are underway for a wide array of solid tumours, including triple-negative breast cancer (which is a type of cancer that doesn't have the same receptors that are usually found in breast cancer), head and neck cancers, osteosarcoma, and anaplastic thyroid cancer (Anderson et al., 2015).

In the present day, TIL therapy is seen as a last resort and considered a backup plan because it is a highly labour-intensive and expensive method. There are many treatment plans and intervals for each person and each tumour meaning patients may require hospitalization for several weeks. The majority of patients using this method are already very ill, so they cannot wait for the approval and the preparation time needed to start the treatment. Some doctors will save TILs from a tumour in case of a reoccurrence of the tumour.

TCR-T cell Therapy

Located on the surface of T cells, there are TCRs which are specific and characteristic markers. Genetically engineered, they recognize particular antigens present in tumours. It is difficult for TCRs to bind to tumour antigens in the human body because the affinity of TCRs to antigens is relatively low. Doctors could create TCRs with high affinity to specific antigens and then encode them onto T-cells by using genetic engineering.

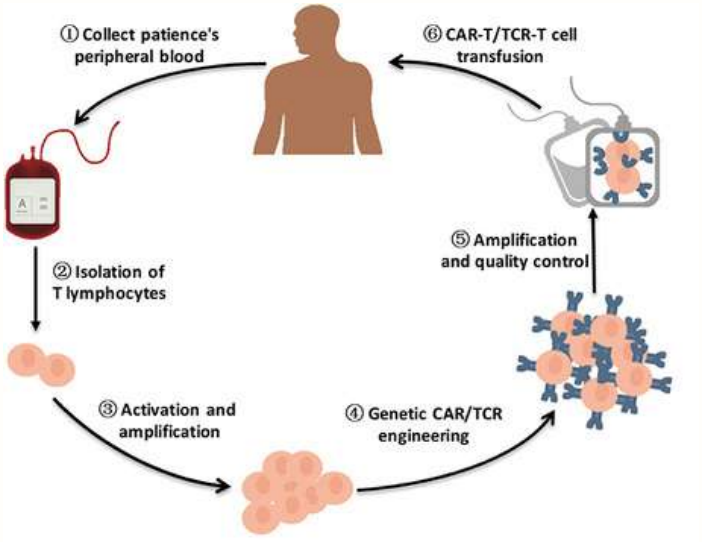

Fig 2: *Process of TCR-T cell therapy*

Doctors must identify a specific cell target before genetically engineering high-affinity TCR-T cells. This genetic engineering process is as follows: Blood is collected from the patient, and the T-cells are isolated. The polypeptides present in cancer cells are identified, and the polypeptides present in normal tissue are removed.

Following confirmation of the target, TCR phage displays are generated (which are used to identify epitopes [the binding sites of antigens]) to screen highly specific and affine TCRs. Doctors will infuse the blood into the body via an IV following the transfusion. A preclinical trial will be performed to ensure that potential off-target antigens do not have a significant impact.

A study by Aaron P Rapoport, Edward A Stadtmauer, Gwendolyn K Binder-Scholl, and Michael Kalos found that when the affinity of essential amino acids was changed in modified TCRs, tumour-associated antigens (TAAs) increased significantly. The TCR-T cells could also be used to treat cancers overexpressing the antigen NY-ESO-1, like multiple myeloma. The altered TCR caused a complete or near-complete response in about 70% of patients with multiple myeloma in the clinical trial.

During TCR-T-cell therapy, TCR-T cells recognize any antigen tagged with major histocompatibility complex [MHC] molecules (MHC is a set of genes that codes for the protein on the surface of cells that assists the immune system in recognizing foreign substances). There has been an exponential improvement in the affinity of TCRs for cancer cells and TCR-T cells in identifying the internal molecules of cancer cells. In the presence of even a small amount of antigens from cancer cells, TCR-T cells will be activated, resulting in the subsequent killing of the cell. However, these TCR-T cells can only stay alive for about six months or less after treatment.

TCR therapy, however, is expensive and time-consuming. The TCR-T-cell's capabilities are also limited by MHC class, and often there is a risk of mismatching. Increasing the affinity of TCRs could potentially increase the risk of false targeting. The antigens must also be located outside the cell for the treatment to work.

There are currently clinical trials for TCR-T-cell therapy in malignancies (leukaemia, lymphoma, multiple myeloma) and solid tumours (Rapoport et al., 2015).

Chimeric Antigen Receptor [CAR] T-cells

CARs, or chimeric antigen receptors, are a type of synthetic protein engineered to bind to the surface of cytotoxic immune cells (like T-cells). They have the enhanced ability to recognize and eliminate cancer cells. Contrary to TCR-T-cell therapy, CAR-T cell do not only target cancer cells' surfaces. Known as recombinant receptors, CARs can bind to tumour antigens and activate T-cells.

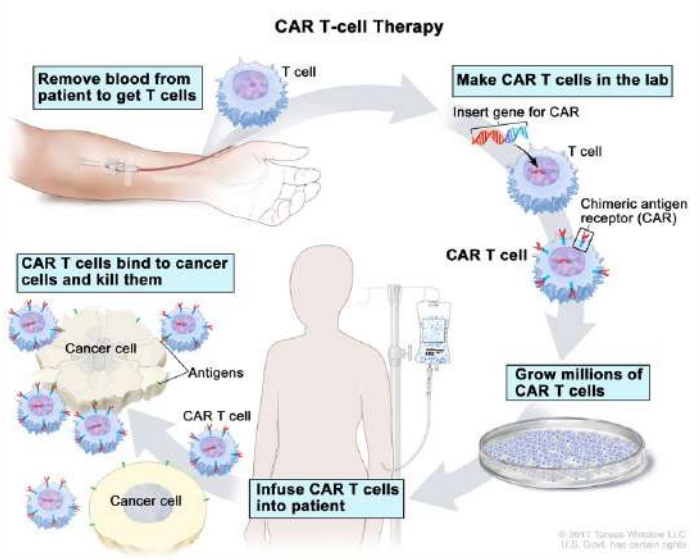

Fig 3: *What happens to cells in CAR-T cell therapy*

CAR-T cells are typically produced in five steps according to the prototypical process. Before the transfusion, patients will undergo preconditional chemotherapy to shrink the tumour. To begin with, a cancer patient's T cells must be isolated. Doctors will create the CAR-T cells in a laboratory in the second step by inserting CAR genes into T-cells. Thus, the T-cell will simultaneously recognize tumour cells and be activated by CAR genes. A third step involves cultivating CAR-T cells ex vivo (outside of the body) and stimulating them with cytotoxins (small proteins that regulate the immune system and blood cell activity).

Having received the CAR-T cell, the fourth step involves transfusing them back into the patient. The patients will also be monitored for any severe physical reactions their bodies may have to the treatment.

A signal initiated by the antigen-binding domain triggers the specific killing of cancer cells upon recognizing the malignant antigen in CAR-T cells. CAR-T cell therapy has shown great promise in treating B-cell lymphoma/leukaemia, and some patients have achieved complete remission.

A patient goes through this process over three weeks: two weeks to prepare the cells for infusion and one week for the CAR-T cell to be transfused back into the patient. If any CAR-T cell remains after expansion, they can be frozen and used in the future.

The success of CAR-T therapy can be seen in the case of Emily Whitehead. She was diagnosed with acute lymphoblastic leukaemia, a type of blood cancer when she was just six years old. Despite 16 months of chemotherapy, Emily's cancer was resistant, and by the time it relapsed, her family was told she was unlikely to survive. In the wake of this news, Emily's parents, Tom and Kari Whitehead decided to enroll in a CAR-T cell trial, and the treatment worked! Her condition went into complete remission, and she was discharged from the hospital at seven years old. As of 2021, she is still cancer-free. Her parents created the Emily Whitehead Foundation in her honour after her experience with cancer and her success story with CAR-T cells.

CAR NK Therapy

This kind of therapy is similar to CAR-T cell therapy. Natural killing [NK] cells are used to treat cancer and can attack germs and malignant cells, but their antigens are not specific. They are capable of detecting and killing any untoward cells. The problem is, that they don't live long enough or multiply fast enough to be effective against cancer cells, so they can't eradicate them.

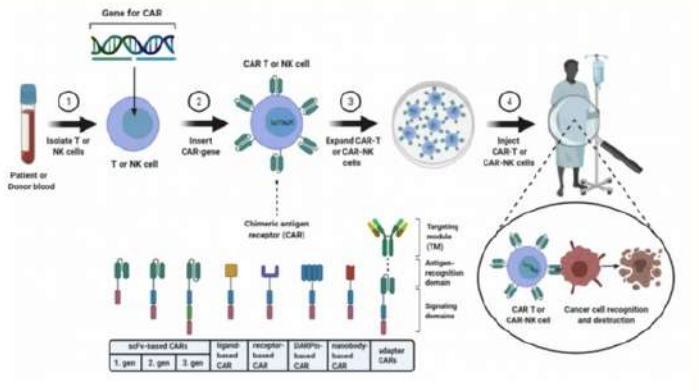

Fig 4: *What happens to cells in CAR NK therapy*

To manipulate the NK cells, doctors use cytotoxins. NK cells will become more robust and durable from exposure to cytotoxins, making them more effective against cancer cells. Additionally, CAR has also been used to make NK cells more defensive by enhancing them in some cases. While other T-cell therapies are obtained from patients, NK cells are obtained from donors.

A CAR NK therapy begins by first collecting NK cells present in the umbilical cord blood after the baby is born. Doctors will then insert the CAR onto the surface of the NK cell. By adding CAR, the NK cells can recognize cancer cells. In preparation for the transfusion, patients undergo chemotherapy. This procedure does not shrink or treat the tumour, but it helps the body prepare for the transfusion of CAR-NK cells. After chemotherapy, CAR-NK cells are intravenously transfused into the patient's vein.

There are significantly few side effects compared to other types of adoptive cell therapy, and most of them result from the conditioning chemotherapy rather than the CAR NK cells themselves. The patients will experience nausea, low blood counts, and weakened immune systems.

Anderson Cancer Centre uses CAR NK cell therapy to treat chronic lymphocytic leukaemia, non-Hodgkin lymphoma, and acute lymphoblastic leukaemia (Carter, 2020).

CONCLUSION

The death rate associated with cancer is among the highest in the world. However, we are getting closer to a potential cure every day, thanks to the many people who work tirelessly to help find a cure. It is predicted that immunotherapy will continually advance to become a cure for more types of cancer. The race to cure cancer has already begun.

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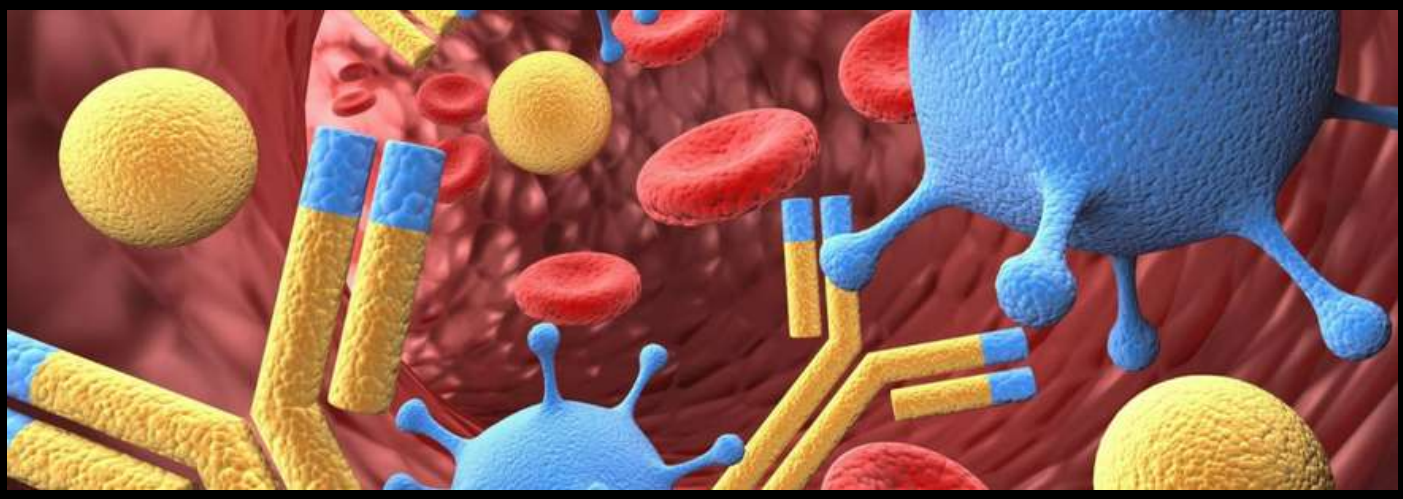
B Cells: Formation & Immunisation

Jacque Ho 11W

INTRODUCTION

Following the recent pandemic, global scientists and legislators completed the development and distribution of safe and effective vaccines against COVID-19. These Vaccines activate B-cells to generate long-lived plasma cells capable of producing protective antibodies against the coronavirus, as well as immunological memory cells that provide increased and sustained protection upon re-exposure. The body's B cells are specialized white blood cells that undergo the process by producing antibodies that are crucial for this protection strategy and are responsible for nearly all vaccination successes. However, in recent years, questions of how B cells function in the human body have arisen. What is the B cell? How does it boost our ability to respond to new infections and variations? How does it generate a successful and lasting immunity against pathogens? These questions will each be answered in this article.



WHAT IS A B CELL?

Humans are constantly exposed to microorganisms that can create a substantial risk to their health. Due to these circumstances, we ultimately rely on our immune system to protect us against the presence of these harmful pathogens. With that said, immunology is the name given to our protection mechanism in the body; it lowers the chances of being infected and keeps us from becoming reinfected. The name B cells comes from their place of maturation- the bone marrow.

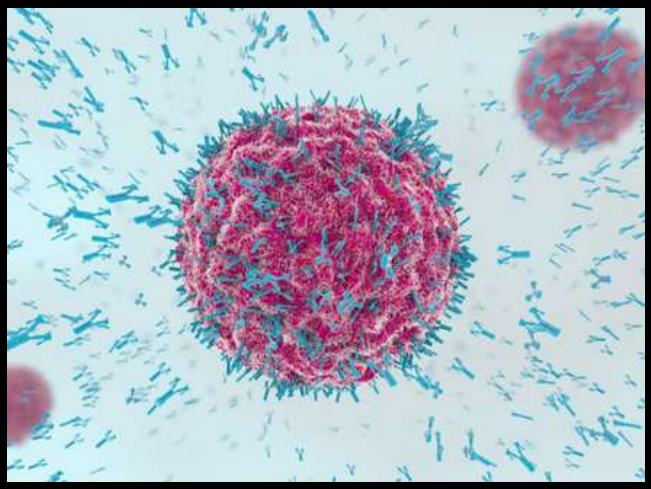
These cells form in the germinal centers (specialised microstructure); they memorize properties of the antigen during an initial infection, so when encountered again, the memory B cell will initiate a faster secondary immune response. While a human's immune system composed of B cells can successfully destroy the majority of infections, a small percentage can cause the host's mortality if left untreated. A current and crucial example of this is the respiratory virus responsible for causing COVID-19 (Coronavirus).

HOW IS A B CELL FORMED?

B cells develop and differentiate in the bone marrow from stem cells. After maturation, B-cells can be present in the bone marrow, intestine, lymph nodes, and blood. During the primary immune response, B and T cells (lymphocytes) proliferate to produce effector cells and memory cells. More specifically, the main difference between B and T cells is that B cells destroy any pathogens that are not in a body cell while T cells destroy body cells infected by pathogens. Conversely, memory B and T cells that are complementary to an antigen sustain an efficient immune response when encountering the same antigen again. This is known as the secondary immune response.

HOW DOES THE B CELL PROTECT THE BODY AGAINST AN INFECTION BY PRODUCING ANTIBODIES?

When B-cells come into contact with antigens, they mature into plasma B cells in the bone marrow that are able to secrete antibodies (also known as immunoglobulin) in response to the antigens. This is a specific response; each of these plasma cells is only able to secret one type of antibody. Antibodies are globular proteins shaped like a "Y" and are produced by plasma cells in the process of the humoral response.



Antibodies bind to antigens to destroy them. This is called agglutination. Then, antibodies binding to toxins to neutralize the poison are called antitoxin. This kind of binding between an antibody and antigen prevents the microorganism from invading body cells. In some situations, an antigen-coated by antibodies will undergo a reaction with complement (made of 30 proteins) to cause lysis (bursting) and phagocytosis (engulfing) of the pathogen. The synthesis of antibodies continues until all antigen molecules have been eliminated and can last for months in the body to give long-term immunity against the specific antigen.

HOW DOES A VACCINE INITIATE THE PRODUCTION OF B CELLS?

A vaccine uses the secondary immune response to strengthen the immune system without inflicting disease by introducing the body to specific antigens. Vaccines are designed to prepare the body so that when a person is exposed to a pathogen, their immune system can respond quickly and efficiently to kill the pathogen before it causes sickness and reduces the likelihood of disease transmission.

To develop a lasting immunity against pathogens, a vaccine must elicit B-cells to form plasma cells that secrete antibodies and form memory cells through the germinal center (GC) reaction. More specifically, the germinal center consists of secondary lymphoid tissues responsible for producing these B-cells. Here, B-cells undergo mutation when being stimulated with the antigen from the vaccine to clone themselves and generate antibodies with a high affinity to bind antigens. These permanent plasma cells produce complementary antibodies that defend the body against infections.

HOW DOES THE MEMORY B CELL WORK?

A crucial characteristic of a successful and effective adaptive immune response is the capability to provide a faster and stronger response upon encountering the same pathogen; memory B-cells. Once the body has successfully destroyed the pathogen, some B cells remain in the blood as memory B cells. These cells can remain dormant for years at a time before being re-stimulated with the relevant antigen and generate powerful and rapid responses. Both vaccinations and infections trigger memory B cells to multiply; however, they do not differentiate into plasma cells. This provides the body with immunisation.

CONCLUSION

To conclude, B cells play a major and incredible role in the body's defence system against invading pathogens. Antibodies produced by B-cells have various functions: neutralizing toxins produced by pathogens, regulating the effectiveness of immune cells, and eventually destroying the pathogen. Without them, any infection could lead to death! With that said, in the midst of this pandemic, we must be wary of our surroundings and hygiene. Safety precautions for our own health must be taken, so don't forget to go wash your hands before causing an infection!

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Are Laparoscopies the Future of Surgery?

Curtis Yip 11N

WHAT IS LAPAROSCOPIC SURGERY?

Over the past few decades, surgeons and medical researchers have investigated different ways to make surgery safer, quicker, and more effective. Subsequently, minimally invasive operations have been introduced to patients as an alternative to general open procedures, and laparoscopies are one of the most popular and widely used types of surgery.

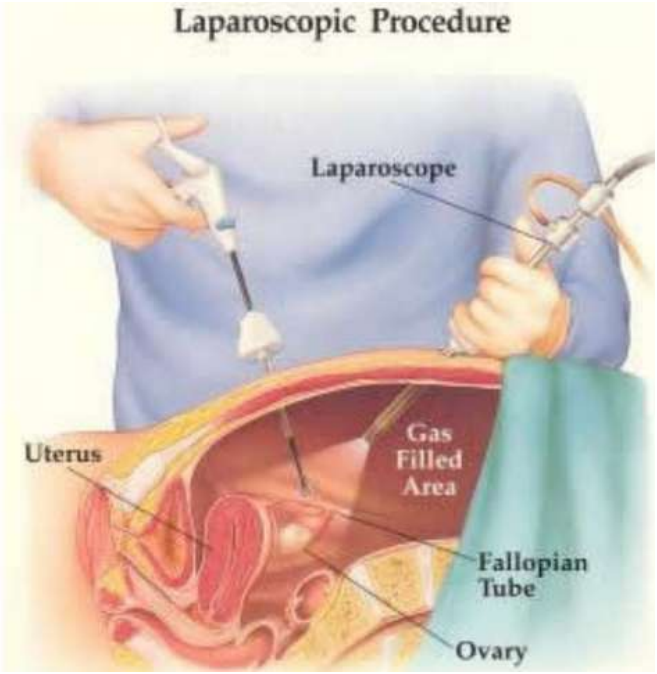
From recent figures, almost around 15 million are performed globally each year, accounting for 6% of all operations. Laparoscopic surgery procedures involve the laparoscope, a tube with a light source and camera at the end, projecting images of the patient's internal environment, for the surgeon to operate precisely.

Laparoscopic surgery is used for various functions. One of the main uses of the technology is to diagnose conditions in the body or conduct biopsies, such as diagnosing pelvic inflammatory disease, endometriosis, appendicitis, etc. Along with the use of diagnosing diseases, it also allows for operations, most commonly in the field of gastroenterology (the digestive system), gynecology (the female reproductive system), and urology (the urinary system). Some of the surgeries include removing a section of the intestine and repairing hernias. The most common procedure is the removal of the gallbladder called laparoscopic cholecystectomy.

HOW IS LAPAROSCOPIC SURGERY PERFORMED?

During the procedure, the patient is normally under general anesthesia, so that they do not feel any pain from the incisions made. However, there are some cases where anaesthesiologists use local anesthesia, with only part of the body numb to any pain.

This inflates the abdomen in order to allow for higher visibility and feasibility for the surgeons to search or operate in the specific area easily. Next, they insert the laparoscope, and the camera attached to the tip displays the images of the body on a large screen next to the operating table. According to images produced, they manipulate the laparoscope to locate the area, where they will operate or conduct findings for a final diagnosis. After the surgery is completed, they take out all the instruments and deflate all the gas out of the patient's body.



This sews the incisions shut with nylon sutures. The patient is then taken to recovery, and they are often allowed to leave the hospital the day of the procedure or after one overnight stay.

THE HISTORY OF LAPAROSCOPY

For us to understand and make predictions about laparoscopic surgery, we must first look at its past and the history it developed into what we recognize as the laparoscope. The first noted use of the laparoscope was in 1902 when Georg Kelling from Dresden operated the device on a dog. 8 years later, in 1910, Hans Christian Jacobaeus from Sweden used the laparoscope and its operative techniques on a human. This was the first recorded clinical use. These 2 are often cited as the pioneers of laparoscopic surgery, introducing its technology to mainstream medicine. Over the next few decades, their techniques and the device itself were refined and improved, and laparoscopy gained even more international recognition.

In 1929, when the camera at the tip of the laparoscopy was invented, it marked a major and revolutionary step in the development of the technology. With the introduction of the camera, surgeons could now use the scope with both hands, since their hands were no longer required to visualize the body. More advanced surgical procedures could now be done with a laparoscope, like organ resections. In 1981, J.C. Tarasconi's use of the laparoscope in an organ resection for the first time was published in an edition of "The Journal of Reproductive Medicine", making it the first to be recorded in any form of medical literature. In the same year, Kurt Semm performed the first appendicitis removal with a laparoscope. The laparoscopic techniques he applied would be imitated and brought into common medical practices.

ADVANTAGES AND DISADVANTAGES OF LAPAROSCOPIC SURGERY

There are several pros and cons when comparing laparoscopic surgery as opposed to standard open surgery. One of these advantages is that the recovery rate is much shorter for patients who had laparoscopic surgery. Since some hospitals treat the types of procedures as outpatient cases, most of them are allowed to leave the hospital the day of the procedure or after an overnight, and their normal activities will be able to resume after a week. Another advantage of laparoscopy is that there is a lower chance of infection; with the incision made during the surgery being way smaller, it lowers the chance of pathogens like bacteria and viruses invading and infecting the body through the scar, reducing the risk of many complications. Finally, the use of pain medications post-surgery is decreased, since there is less pain for the patient as their smaller scar heals, removing the need for massive amounts of pain relievers.

On the other hand, there are some disadvantages of laparoscopy compared to open surgery. For example, there is a considerably limited range of movement for the laparoscope. The incision made by the surgeon is so small that you can only fit the laparoscope in. Therefore, operators may find it difficult to navigate around the body, especially to areas further away from the site of the incision. This could potentially increase the risk of puncturing blood vessels, causing excessive bleeding and leading to life-threatening conditions. In addition, surgeons have a harder time visualizing the patient because laparoscopies solely rely on the camera to locate the area, increasing the challenge for surgeons to operate effectively and with the correct pressure. Finally, bloating is a lot more common after surgery for patients, as the carbon dioxide gas injected to inflate the body wouldn't be fully removed after the surgery.

ROBOTIC LAPAROSCOPIC SURGERY

Over the last 10 years, robotic laparoscopic surgery has been introduced to hospitals and the worldwide medical community. This type of procedure involves using robotic arms to control the laparoscope instead of humans, making it possible to access organs that surgeons wouldn't be able to reach with hand-held laparoscopes. It lowers the complications caused by human-induced errors like shaking hands, which are especially prevalent when dealing with delicate tissues and high-pressure situations.

Consequently, military hospitals or nations in conflict are considering investing in robotic laparoscopes, as patients can be treated more quickly and effectively. One of the most well-known devices is the "da Vinci" robot, performing thousands of surgeries since it was introduced. However, the costs for these technologies are extremely high, requiring around 2 million USD in order for hospitals to obtain one. Furthermore, there has been limited evidence of improved outcomes with the use of robotic-assisted surgery compared to its traditional counterpart, affecting the demand for these pricey devices.

ARE LAPAROSCOPES THE FUTURE OF SURGERY?

In conclusion, it is my opinion that laparoscopies will continue to increase in popularity and accessibility to patients, and more surgeries will become possible with the use of a laparoscope, but it will most likely not be the most popular option in the short term. While there are much lower infection rates and faster recovery times, the technology could still be developed even further, lowering the chances of complications. One way they can continue to enhance the laparoscope is to have some sort of measurement of the pressure applied to the organ, letting the surgeon know the most suitable way of operating. Moreover, the tube could be made with more flexible material to make it easier for the surgeon to navigate the body, increasing perception when controlling the device. However, once the laparoscope's technological enhancements have reached a certain stage where nearly all surgeries can be done the most effectively with a laparoscope, and the tool is financially and physically accessible to most patients, it would probably take over the surgical industry and become the future of medicine.

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How Can Biotechnology Help Cure Cancer?

Pearl Ghevariya 12E

WHAT IS BIOTECHNOLOGY?

Biotechnology is a wide range of areas in Biology. It is the application of living systems and cellular processes to the development of technologies and goods that can benefit both our lives and for a better environment. An example is that we have harnessed microbes' biological processes to produce important food items like cheese and bread, as well as to preserve dairy goods. There is a wide range of biotechnology including medical, food, environmental and agricultural (plant) biotechnology.

This article will be mainly focused on biotechnology in medicine. There is a wide range of biotechnology including medical, food, environmental and agricultural (plant) biotechnology. This article will be mainly focused on biotechnology in medicine. Modern biotechnology in medicine offers ground-breaking goods and tools for combating chronic diseases. An example is that it has effectively and successfully extracted polypeptides and proteins from a novel class of potential medications. To add on, another example are interferons, which are a type of signaling protein that is produced and released by the host cells when there is the presence of certain viruses. It causes the infected cells and those adjacent to produce proteins that inhibit the virus from replicating (interferon | biochemistry, n.d.). Interferon is created by genetically altering organisms. This can then be used to treat a certain type of leukemia (a type of blood cancer) in adults, however additional uses and development for future therapies to a broader spectrum of malignancies and other disorders are hoped for.

SITU HYBRIDIZATION AND IMMUNO-ONCOLOGY

Situ hybridization(ISH) is a technique that employs tagged probes to detect RNA and DNA which are inside cells. This approach is beneficial for finding genes associated with the occurrence and development of cancer.

Immuno-oncology is when you don't target the tumor, but instead use the immune system to prevent and eradicate it. Immuno-oncology also gives the immune system a long-lasting memory of the tumor cells so it can respond quickly to the cancer if it reoccurs.

GENE THERAPY

Gene therapy works by using specific nucleic acid sequences that can be delivered to the patient to the area of the body which is needed (target cell), which will be then introduced into the cell's genome and expressed in the same way as other genes would. By doing this, it would mean the gene will be able to be used to activate a certain activation path or it could even be translated as a protein. Adenovirus and Lipofectamine are two main types of vectors that exist in this therapy. Adenovirus uses viruses and Lipofectamine which is a type of liposome (a spherical vesicle) and can pass through freely the cell membrane and deliver.

CONCLUSION

There are many different ways in which biotechnology can help treat cancer. However, it is very difficult when using it as cancer cells keep changing the way they behave over some time. This makes it very hard to do the treatment, the cancer cells could start being resistant to the treatment and then the treatment will start being ineffective. Although it is a very difficult process, the world is developing and still growing with different technologies, in the future there will be a very efficient way Cancer can be cured. The treatment varies among each person.

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Chemiluminescence

Clarence Ki 11F

Have you ever cracked a glow stick, or seen animals that glow? For those things to happen, a process known as chemiluminescence occurs. Chemiluminescence is a form of luminescence, which means the emission of light that is not from heat. Therefore, chemiluminescence is the emission of light due to a chemical reaction. There are many applications of chemiluminescence, such as in glow sticks, in forensics, in living organisms, to detect small amounts of elements in cells, and many more.

HOW DOES IT WORK?

There are two ways this could happen, either through "direct de-excitation", or "indirect de-excitation". Both processes start the same way in which two reactants react to form a high energy intermediate. A general chemical equation for this initial reaction can be written as:

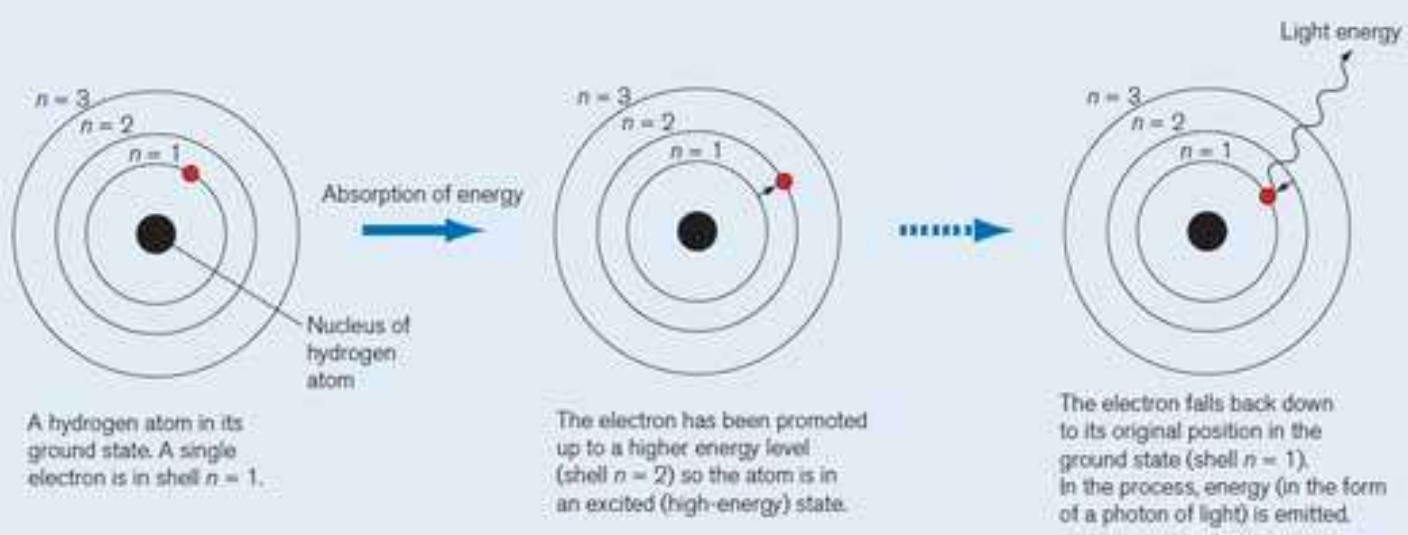
$A + B \rightarrow C^* + D$

where C* represents the excited intermediate (Braun, 2017).

The excited intermediate occurs due to promotion of an electron to a higher orbital than its ground state, making it unstable. This is because electrons have higher energy at higher orbitals. When the electron goes from a higher orbital to a lower orbital, energy is released in the form of a photon. The lowest orbital an electron can occupy, and therefore the lowest energy and most stable form of the particle, is called the ground state.

INDIRECT DE-EXCITATION

If it is through indirect de-excitation, the high energy intermediate gives its energy to another secondary molecule such as a dye, fluorophore, phosphore or sensitizer. A fluorophore is a chemical compound that can undergo fluorescence, which means it can absorb light, and re-emit it. Phosphore is also a chemical compound that can absorb light, and re-emit it, however, it is not exclusive to fluorescence only(phosphorescence is included). That secondary molecule relaxes to the ground state, which releases a photon.



Electron going to ground state and releasing a photon

The general chemical equations for indirect de-excitation can be written as

$C \rightarrow C + Dye^*$

$Dye^* \rightarrow Dye + Light$

(Braun, 2017)

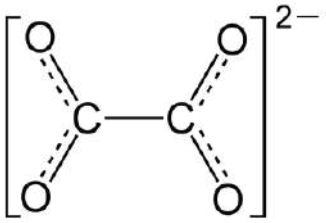
IN GLOW STICKS

The chemical reaction of glow sticks is an example of an indirect de-excitation chemiluminescent reaction, as the reactive intermediate for the reaction gives an electron to the dye, which then produces a glow as shown in the image below.

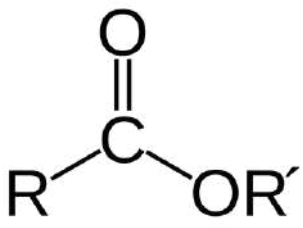
Glow sticks contain an outer casing and an inner glass tube. The outer casing contains an oxalate ester, and a fluorescent dye or sensitiser. The inner glass tube contains a hydrogen peroxide solution.

There are many different oxalate esters and dyes that can be used, and the dyes used affect the colour of the glow.

When you bend the glow stick, the glass tube in the middle cracks, and hydrogen peroxide solution comes in contact with the oxalate ester and dye solution. The oxalate ester reacts with the hydrogen peroxide to form 1,2-Dioxetanedione. The 1,2-Dioxetanedione receives an electron from the dye, and breaks down into carbon dioxide, and a negatively charged carbon dioxide radical anion (Halford, 2021). The dye, after losing an electron, becomes a positively charged radical cation.



Oxalate Ion



Ester Functional Group

A free radical is a particle with at least one unpaired electron in its outer shell (unpaired electrons occupy an orbital as a single electron, as opposed 2 electrons with opposite spin). Usually, electrons in covalent bonds come in pairs. The unpaired electron in the radical causes it to be chemically reactive due to its instability. Hence, they usually will react with another radical to form regular molecules, or react with regular molecules to form new radicals (Walling, 2018). Atoms are most stable when they have 8 electrons in their outer shell(octet rule), therefore the dye will take back an electron from the negatively charged radical anion. By gaining back the electron, the dye gets excess energy, which causes it to go into an excited state. When the excited dye relaxes and drops to the ground state, a photon is released.

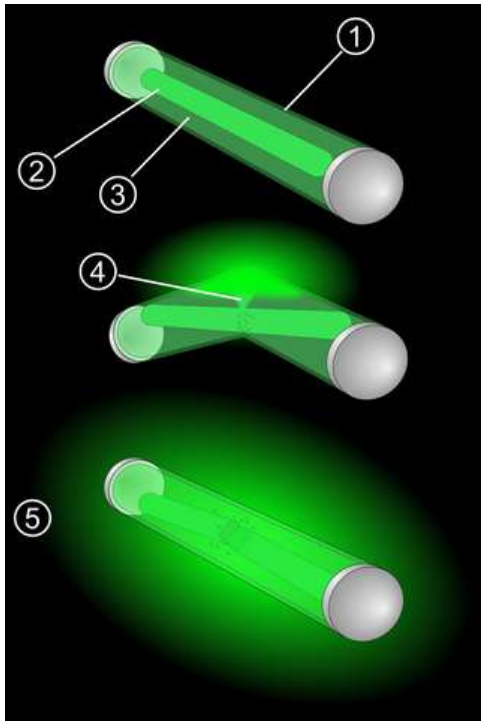


Diagram of glow stick

FORENSICS

Chemiluminescence can be used in forensics to detect trace amounts of blood. To do this, a chemical called luminol is used. Luminol has the molecular formula of C8H7N3O2. A mixture of luminol and hydrogen peroxide in basic conditions can be sprayed on an area trace amounts of blood. As the reaction is quite slow without a catalyst, a glow is difficult to see.

(A catalyst is a substance which increases the rate of reaction by providing an alternate pathway for the reaction to occur at a lower activation energy, while not being used up). The iron contained in the blood acts as a catalyst which increases the rate of reaction and causes a glow to be seen when the mixture is sprayed on it (Harris, 2002). Very little blood is required for it to catalyse the reaction so that even if the blood is wiped away or cannot be seen, the reaction can produce a glow.

Luminol reaction in beaker

FIREFLIES

Fireflies

Fireflies glow for a multitude of reasons. Larvae can produce steroids which make them taste bad for predators. To show that they taste bad, they will glow. For adult fireflies, many have flashing patterns that are unique to that specific species of firefly, which could be used to identify members of the same species. Furthermore, firefly flash patterns could be used to show members of the same species that are of the opposite sex, and to attract a mate. (Branham, 2005) To glow, fireflies have to use what is known as bioluminescence, which is a form of chemiluminescence.

Fireflies contain what is known as firefly luciferin, which is also known as D-luciferin, and have enzymes called luciferase (Luciferin is a generic term for chemiluminescent compounds in organisms). The word equation for the reaction can be shown as:

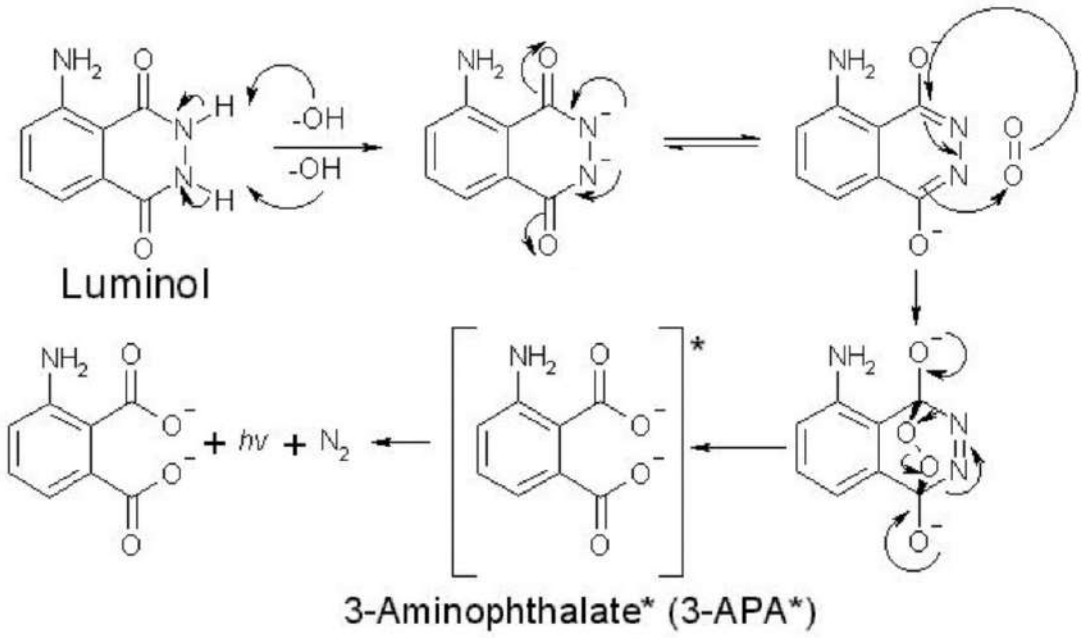
$$\text{Luciferin} + O_2 + \text{ATP} \xrightarrow{\text{Luciferase}} \text{Oxyluciferin} + CO_2 + \text{AMP} + \text{PPi} + \text{light}$$

A word equation can be written to demonstrate the chemical reaction:

Luminol + Hydrogen Peroxide → 3-APA* → 3-APA + Light.
("Luminol - Wikipedia", 2022)

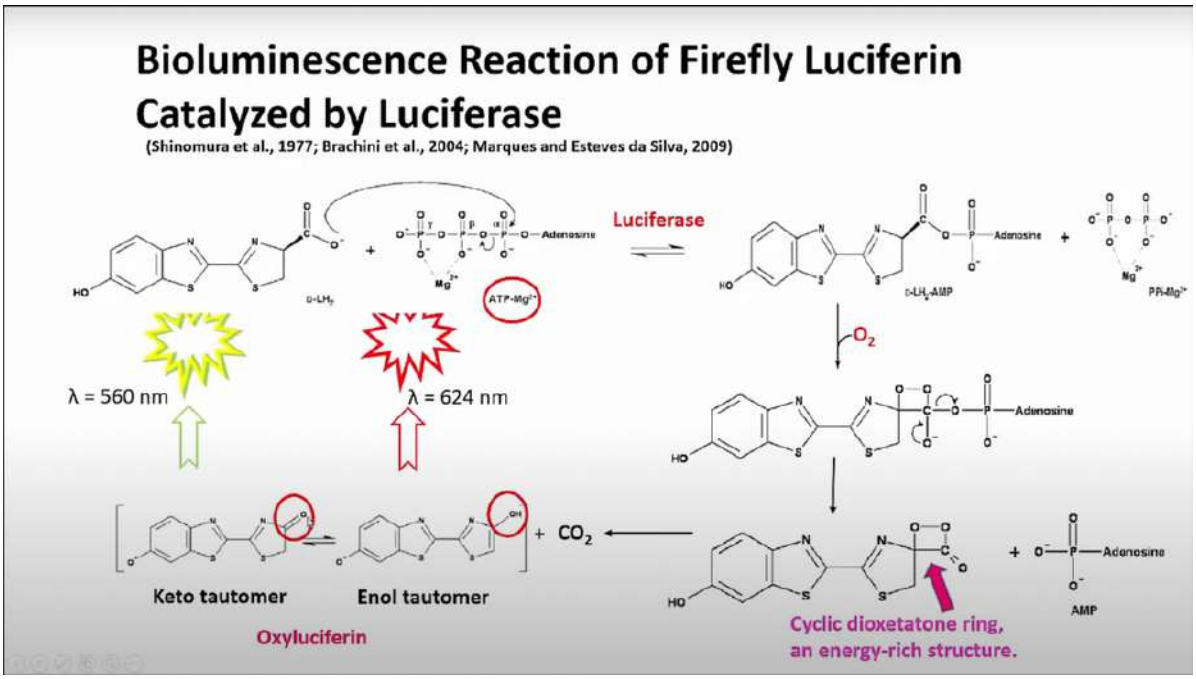
In this case, 3-APA* (3-aminophthalate*) is the reactive intermediate that relaxes to the ground state, which releases a photon.

Luminol can also be used to detect nitric oxide levels, as luminol can react with nitric oxide to produce the reactive intermediate(Martínez, 2021). The process of the chemical reaction of luminol and hydrogen peroxide is as follows:



Luminol reaction diagram

Firstly, the compound (Luminol) is "deprotonated", which means that H+ ions are removed. Hydroxide ions (OH-) are present in water, which react with the NH groups, and take the H^+ away from the Nitrogen to form water (H2O), which causes each nitrogen atom to have a negative charge. This turns the luminol into a dianion (an ion with a -2 charge is called a dianion). The electron is more stable in the oxygen than nitrogen, and so the 2 electrons go to the 2 oxygen atoms to form 2 oxide ions. The dianion then reacts with oxygen (O2) produced by the decomposition of Hydrogen peroxide (H2O2) to form an endoperoxide. An endoperoxide is a heterocycle with a peroxide bond inside the ring.(A heterocycle is a ring with 2 or more elements, one of which is typically carbon.) The endoperoxide is then broken down into the reactive intermediate 3-APA*(Goel, 2021). The excited electron in 3-APA* then relaxes into the ground state , which produces light with a wavelength of 425 nm ("2.1: Luminol", 2020), which produces a blue glow.



Reaction of firefly luciferin

Luciferin reacts with ATP(adenosine triphosphate) in the active site of Luciferase (ATP is used to release energy in biological organisms).

This produces Luciferin-adenosine monophosphate(Luciferyl-AMP). Luciferyal-AMP is then oxidised by Oxygen(O2)(Belanger, 2018). Adenosine monophosphate is then removed from the Luciferyl-AMP to produce dioxetane (Stupalo, 2020). CO_2 is then removed from the molecule to produce an excited oxyluciferin. Oxyluciferin then returns to the ground state, and emits a photon with a wavelength of 568 nm, which we see as yellow light. (Stupalo, 2020).

CONCLUSION

Chemiluminescence is used for many things. It is used in glow sticks to create its glow, it can be used in forensics to detect blood, and used in fireflies to deter predators. As a chemical absorbs energy from a chemical reaction, it causes an electron to be in an excited state at a higher energy level. When this electron returns to a ground state, a photon is released. If this photon has a wavelength within the visible spectrum, we will be able to see it.

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Chaos Theory

Alex Sallustro 11F

INTRODUCTION

To make the world what it is today, a complicated and intricate series of events has to have happened in the perfect order, even without the smallest disturbance or change in circumstances. The intricacy of this extends absurdly that even one single slight change in the initial events would result in things taking a complete direction. For example, a common analogy used is that a butterfly flapping its wings in China will result in a hurricane happening on the opposite side of the globe. This analogy can be supported by scientific claims and statistics.

BRIEF EXPLANATION

Before approaching all the maths and physics involved with the discovery, development, and application, one must first understand the fundamentals of this complex system. Chaos Theory is a field of study that focuses on seemingly random statistics or actions that may cause a large effect on Earth. It suggests the statistics are highly sensitive and thus a small change in the initial results could lead to an entirely different end result.

DISCOVERY

Chaos Theory was discovered by Edward Lorenz. Lorenz was a meteorologist who started off his career in the U.S. Army Air Corps with weather forecasting after receiving degrees from Dartmouth College and Harvard University in mathematics. He then progressed to the position of a professor at the Massachusetts Institute of Technology after receiving his master's degree, from which he became the head of the meteorology department. His job was to predict the weather as accurately as possible. For a long period of time, Lorenz developed his prediction from a few days to a whole month. One day, he decided to take a coffee break and left his computer running in the background...a decision that changed the future of forecasting and millions' opinions regarding the world.

The way the program works, or the "Lorenz Equation" as it would be called later on, is that by plugging in equations and statistics, the program simulates a sequence of waves of a graph. Lorenz wanted to look at a specific trajectory in detail

that day so he typed in all the statistics, started the processing, and went to take a break. When he returned and saw the completed simulation, he noticed that the results obtained were extraordinarily different from what he had anticipated. The two graphs started off on almost the same line. However, as the simulation continued, the lines started branching off, eventually leading to drastically different end results that could not have been expected to come from the same parameters. This is shown below in figure 1.

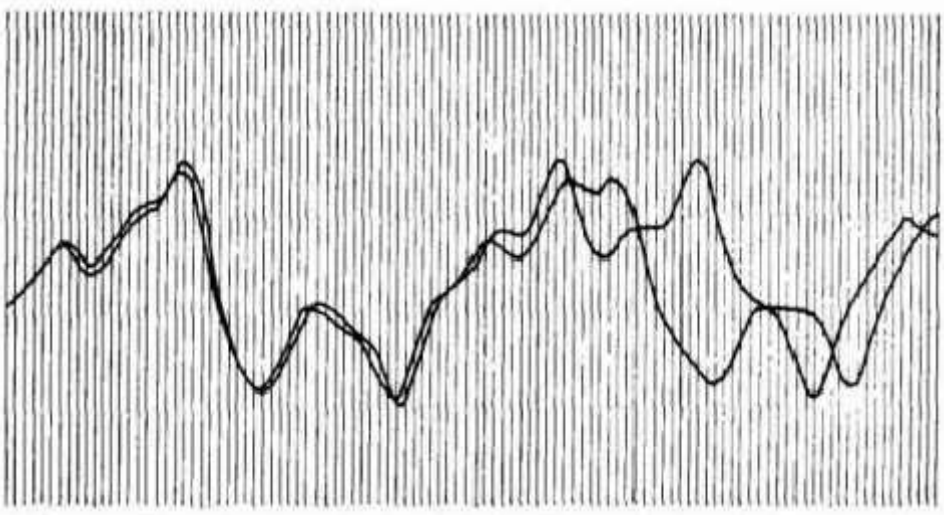

Fig 1: *Simulation of the graph*

Shocked by his findings, Lorenz double-checked his results, computer, and re-ran scans. Eventually, he figured out that the problem was something minute - rounding up. The first line on the graph had the proper parameters, 0.506127. However, the graph that was rounded down to 0.506 shows a drastic difference in results. The discovery that a value as small as 0.000127, could cause such a large difference led Lorenz to think about its applications in the real world, and eventually apply it to estimate the change in the weather. Eventually, his findings led him to his final conclusion, that no matter the scale of the initial matter, extreme results can be generated. Lorenz proposed the idea to his colleagues, and the famous quote was developed; "The flapping of a butterfly's wings in China can cause a tornado in America".

IN-DEPTH UNDERSTANDING OF THE BUTTERFLY EFFECT

$$\frac{\mathrm{d}x}{\mathrm{d}t} = \sigma(y - x),$$

$$\frac{\mathrm{d}y}{\mathrm{d}t} = x(\rho - z) - y,$$

$$\frac{\mathrm{d}z}{\mathrm{d}t} = xy - \beta z.$$

Fig 2: *Lorenz Attractor (Lorenz equation)*

The Chaos Theory revolves around the Lorenz Equation, sometimes referred to as the Lorenz Attractor. It is 3 sets of differential equations to calculate and model some of the unpredictable weather that is happening in the Earth's atmosphere. In the equation, x, y and z are the variables whilst sigma, beta and rho are the constants. Rho is often used in physics to represent the density and in this case, the density of the atmosphere. Sigma is used in physics to represent standard deviations, essentially the amount of variability in a set of data. The common parameters used for this equation are sigma being 10, rho being 28, and beta being 8/3 as these are the numbers and constants in the atmosphere.

The variants in this equation are x, y, and z. x is the proportional rate of convection measured in watts per metre squared per kelvin ($W/m^2/K$). Imagine the atmosphere as a grand ocean, where hot water rises and cold water sinks, allowing for the calculation of the rate of convection. The y and the z in the equation are the horizontal and vertical temperature variations, both measured in degrees celsius. When the equation and constants are input into a 3D graph, it displays the famous butterfly effect graph.

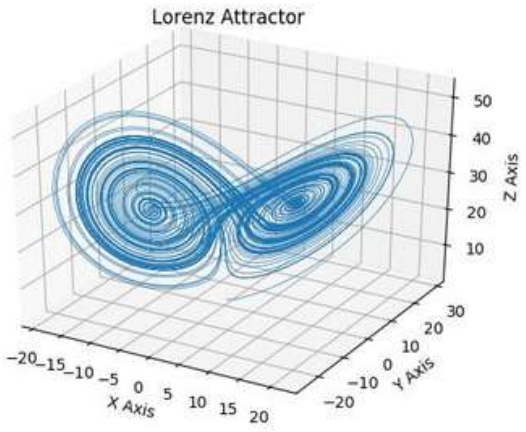

Fig 3: *Lorenz Attractor Generated Graph*

Based on Figure 3, there are two critical points on the graph -- the points that the lines circle around. Even though the movement of the lines on the graph may appear completely random and chaotic, it has a clear outline. There are still limitations as the graph still has a minimum, a maximum, and points that it will not cross. The graph suggests that things that appear random at first glance may not be random when one zooms out and look at the bigger picture from a different perspective.

REAL LIFE APPLICATION

As the Chaos Theory was founded and developed by a meteorologist trying to predict the weather for a longer period of time, the main application of the Chaos Theory is for weather forecasting. Some weather services do "Ensemble forecasting"; taking the Lorenz equation and inputting a large range of initial observations.

The observations are collected from twenty inputs; perturbations, which are selected spots on Earth whose values are so enormous, that they are considered anomalies by meteorologists. By taking the average of the calculated values and selecting the most plausible outcome, the weather can be predicted.

An easy way to demonstrate the law of sensitive dependence on initial conditions is by using a double pendulum; a circle attached to a stick attached to a circle attached to another stick that is swinging freely - which is the double pendulum showed on the right.

However, something so simple to make and imagine actually has extremely unpredictable behaviour. The double pendulum actually consists of a very complicated system where even just a single nanometer of difference in the release height would lead to a completely different result. So much so that even Einstein himself would not have been able to predict the exact movements of the pendulum.

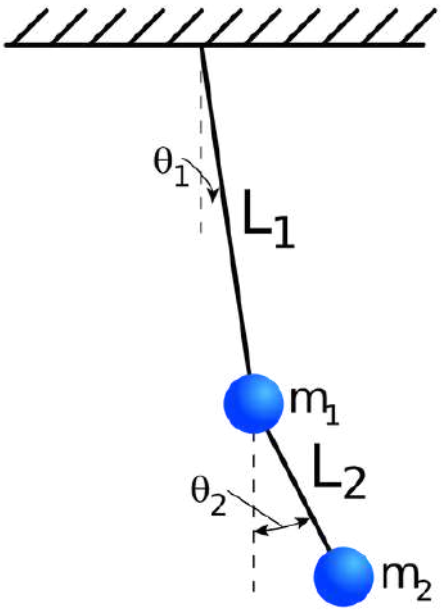

Fig 4: *Double Pendulum*

CONCLUSION

The butterfly effect in Chaos Theory proposes that minute actions or thoughts can lead to large-scale outcomes that can impact everyone and change the course of history. From the moment you laid your eyes upon this article to the present moment, you have made an unimaginably large impact on yourself and everyone around you in the world.

Our past actions and thoughts determine and sculpt our future. Since Lorenz's discovery, we have progressed from Newton's work of determinism to chaos and unpredictability (everything is now chaotic and predictability is far from our grasp). We are able to accurately predict the movements of planets and celestial bodies a thousand years from now, but not the direction and strength the wind will blow in the next hour.

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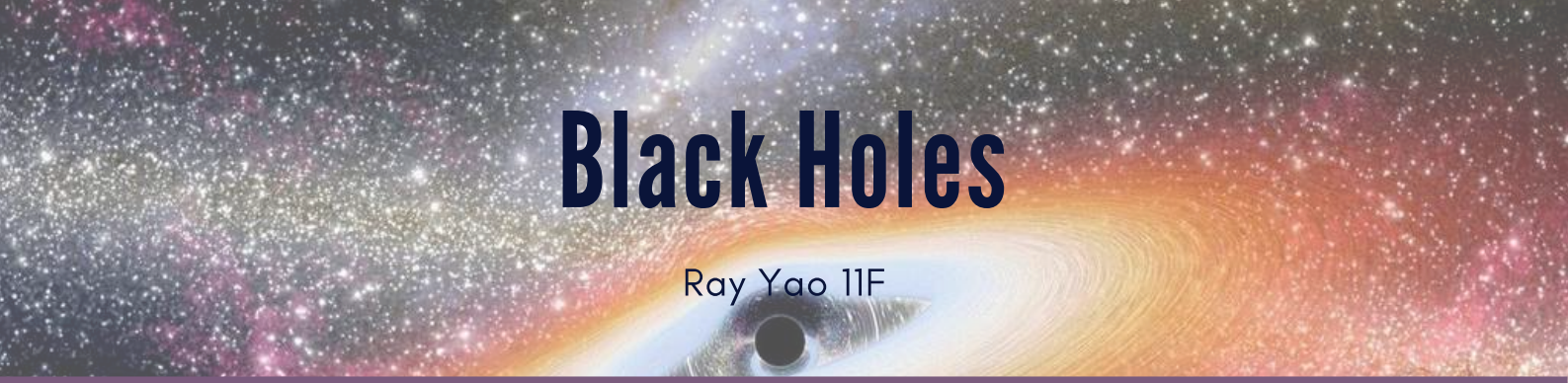


Black Holes

Ray Yao 11F

INTRODUCTION

Nearly 250 years ago, the first prediction of a black hole was made. Many astrophysicists, including the late great Stephen Hawking, disregarded their existence. However, it wasn't until 1971, that a mysterious source of X-rays was confirmed to be the first black hole discovered, known as Cygnus X-1 (Buongiorno, 2021).

Black Holes, one of the universes' most mystifying and perplexing phenomena. An infinitely dense plane with the capability to swallow stars hundreds of times bigger than ours, stealing the life away from them. From being vividly displayed in the movie "Interstellar" to the widespread image of the first black hole, Messier 87, captured by the Event Horizon Telescope, the public perception of black holes has been one that is bursting with wonderment. In this article, I will be discussing the origins and development of our understanding of black holes since the earliest theories.

FORMATION OF BLACK HOLES

Black holes form when stars with masses millions of times larger than ours undergo their stellar evolution and compress to form them(NASA, 2019). Stellar evolution is essentially the life cycle of a star, from birth to death.

When a star is active, it is constantly undergoing nuclear fusion in its core, which is the process of 2 nuclei merging together due to them being densely packed and forming 1 heavier nuclei(J. Kiger & Freudenrich, 2021). This causes a significant release of energy in the form of thermal and light energy. Extreme temperatures are required to complete the fusion process. In our sun, the core achieves 15 million degrees Celsius whereas other massive stars can reach up to 100 million Kelvin. At these temperatures, hydrogen is no longer a gas, instead it exists as plasma(J. Kiger & Freudenrich, 2021).

This allows for atoms to be stripped from their electrons and move about freely as ions. In a process called the proton-proton chain, hydrogen atoms are smashed together at such high temperatures and pressure that despite the electrostatic repulsion between positive ions, they become forced together and form 1 helium nucleus(PSU, 2021).

In our sun and all other stars, hydrogen most commonly fuses into helium, releasing a massive amount of energy. In this process, hydrogen is being depleted but new helium is being created, as you have four fewer protons than you started with, but one more helium nucleus. The mass of one helium nucleus is smaller than the combined mass of four protons, so mass has been lost. However, the mass that gets lost has actually been converted into energy, put by Einstein's famous equation: $E=mc^2$ (PSU, 2021).

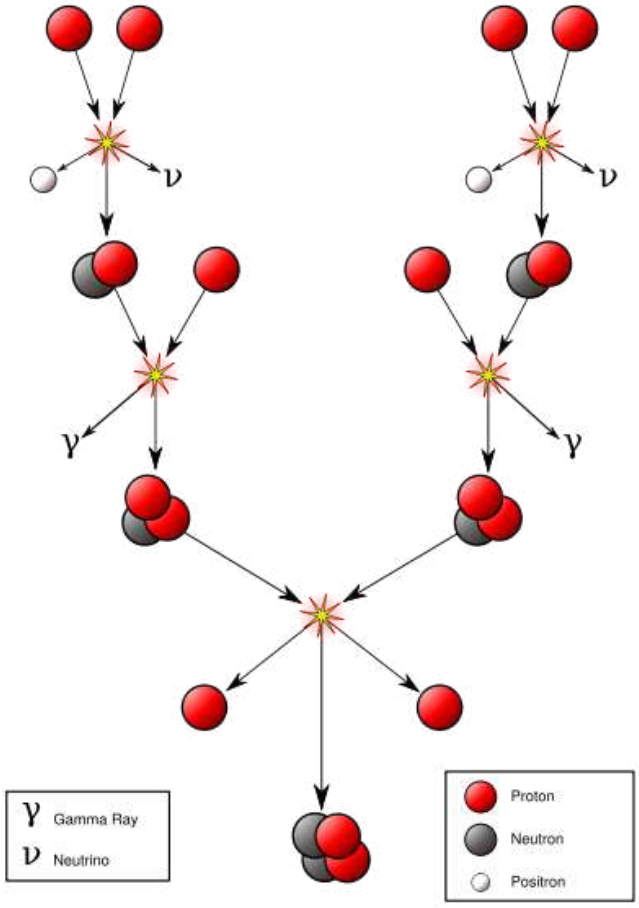


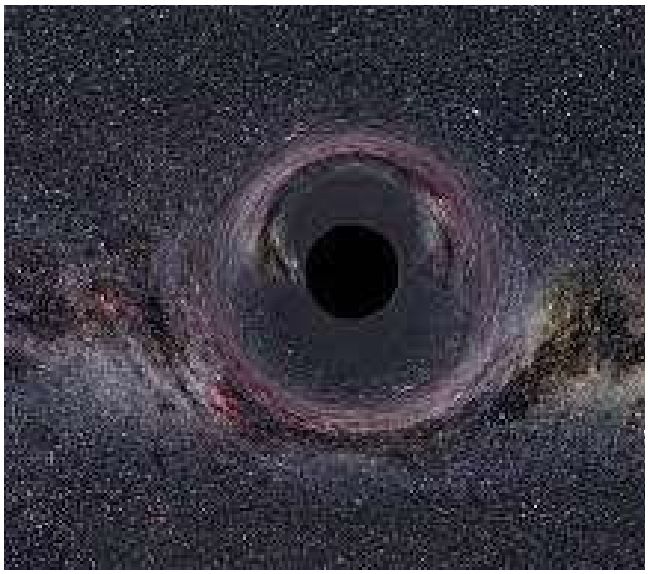
Fig 1: *Nuclear Fusion in the Sun*

The energy, in the form of radiation pushing outwards as photons of light, combined with the thermal pressure maintains a fragile balance with gravity pushing inwards called hydrostatic equilibrium(PSU, 2021). This allows the star to remain stable. Over time, the process of Stellar Nucleosynthesis continues and promotes the fusing of heavier elements until it reaches iron on the periodic table, which occurs as all of the hydrogen has been used up(Kurzgesagt, 2015). More specifically, helium nuclei become the fuel of nuclear fusion, fusing subsequent elements like carbon and oxygen. All stars in the universe cannot fuse iron further which results in the buildup and increase of it in the star, causing the star to be packed densely with it. As it does not fuse, no more energy is released, causing an imbalance in force to combat the compression of gravity, hence the core collapses in upon itself. Ensuingly, at a fraction of the speed of light, the star implodes and dies in a supernova explosion. Stars with a high mass will end up as a neutron star.

However, stars with an incredibly high mass, those millions of times more than ours, will become a black hole. More specifically, a star with a mass 1.44 times more than our own sun will collapse to form black holes or neutron stars, known as the Chandrasekhar limit(Science ABC, 2018).

TYPES OF BLACK HOLES

There are 3 main classifications of black holes in terms of size. Firstly, the smallest of the 3, stellar black holes. These black holes form from stars 2-3 times the mass of our sun due to the gravitational collapse of the star itself(Emeka-Okafor, 2021). However, when compressed into a black hole, it transforms into hundreds of millions of times heavier than our sun. As stellar black holes are relatively tiny in the grand scheme of the universe, they are particularly difficult to detect.



The fact that they absorb all light and is impossible to be photographed directly makes the observation of it even more tedious. Most easily, they can be observed by a system called an X-ray binary(COSMOS, n.d). This is when a stellar black hole is accreting matter into a disk from its companion, a supergiant star, shooting powerful jets of X-rays. X-ray binaries are some of the most vibrant X-ray sources in the universe. Fun fact, the first black hole confirmed, Cygnus X-1, is stellar as it was detected by a large source of X-rays from space.

The largest of the 3, Supermassive black holes, contain up to a billion times more mass than their companion, stellar black holes and form from stars up to millions of times more massive than ours(NASA, 2019). There is thought to be a supermassive black hole at the centre of most large galaxies. In our own galaxy, the Milky Way, it is Sagittarius A*(Britannica, 2015). Direct evidence which supports this shows observations of gaseous particles orbiting at such high velocities at the centres of galaxies can be explained by a supermassive black hole with an incredibly strong gravitational field(COSMOS, n.d). Supermassive black holes are confusing as they do not follow the rate of growth that other black holes comply with. As Dr Muhammad Latif, from the United Arab Emirates University, said, 'It's like going to kindergarten and finding a seven-feet tall baby". Their formation still remains a mystery. One theory is that many clusters of stellar black holes merge together to become supermassive.

Another is that stellar black holes have consumed colossal amounts of gas and particles for millions of years, growing to supermassive sizes(O'Callaghan, 2019). Supermassive black holes can also be detected by their effects on their surroundings.

Have you ever looked at an image of a galaxy and wondered what the shining area of light at the centre is? It is called a quasar which are highly luminous active galactic nuclei that spiral gas and particles at billions of degrees Kelvin(Peterson, 2015). In fact, quasars are the most luminous objects known. They are believed to be powered by a supermassive black hole, which releases massive amounts of energy. This is because gaseous material near the black hole forms into an accretion disk, where it orbits at a fraction of the speed of light due to the strong gravitational forces. It heats up because of friction and releases energy in the form of electromagnetic radiation.

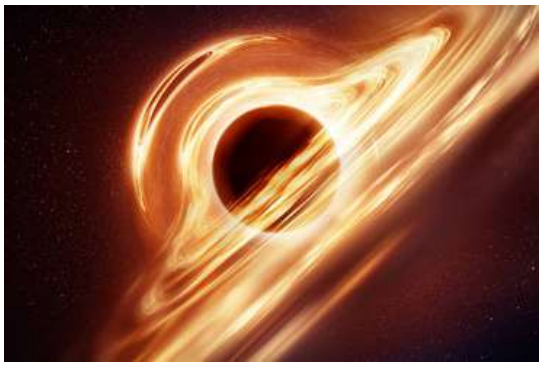


Fig 2: *Illustration of an IMBH*

Because of the astronomical difference between stellar and supermassive black holes, some scientists believe that another type may lie in between, called Intermediate Black Holes(IMBH). IMBH's are hotly debated as their existence has not been confirmed yet. However, NGC 1313 X-1, a black hole discovered, has been calculated to be approximately 5000 times the mass of our sun, putting it in the range of being an IMBH(Parks, 2019). The discovery of medium black holes will be crucial for understanding the formation and evolution of supermassive black holes.

M87 - THE FIRST BLACK HOLE CAPTURED

In 2019, the Event Horizon Telescope captured the first image of a black hole. In the galaxy Messier 87, M87 is a supermassive black hole. Many on social media and online have mocked the infamous blurry image, but what is the reason behind it? To understand so, we must first dive into the question of how black holes can even be captured on image . Due to their nature, even light cannot escape the event horizon, making it impossible for a direct image to be observed, therefore cannot be photographed too. As a result, the only method is to capture the black holes effect on its surroundings. In 2019, the Event Horizon Telescope captured the first image of a black hole. In the galaxy Messier 87, M87 is a supermassive black hole. Many on social media and online have mocked the infamous blurry image, but what is the reason behind it? To understand so, we must first dive into the question of how black holes can even be captured on image . Due to their nature, even light cannot escape the event horizon, making it impossible for a direct image to be observed, therefore cannot

be photographed too. As a result, the only method is to capture the black holes effect on its surroundings.

When gas and dust particles fall towards a black hole, they can build up in what's called an accretion disc, which is shown as the shiny ring around M87. This disc orbits the black hole at 84% the speed of light, generating mass amounts of thermal and light energy due to friction amongst materials as well as the conversion of gravitational potential energy into radiation. Temperatures in black hole accretion discs can range from thousands to several billion Kelvin (Frank, 2016). As put by NASA, 2020, "Some of the material orbiting even closer to the event horizon may be hurled out, forming jets of particles moving near the speed of light that emit radio, X-rays and gamma rays". This radiation can travel across space for hundreds of light years, which is how we can detect the presence and locations of black holes.

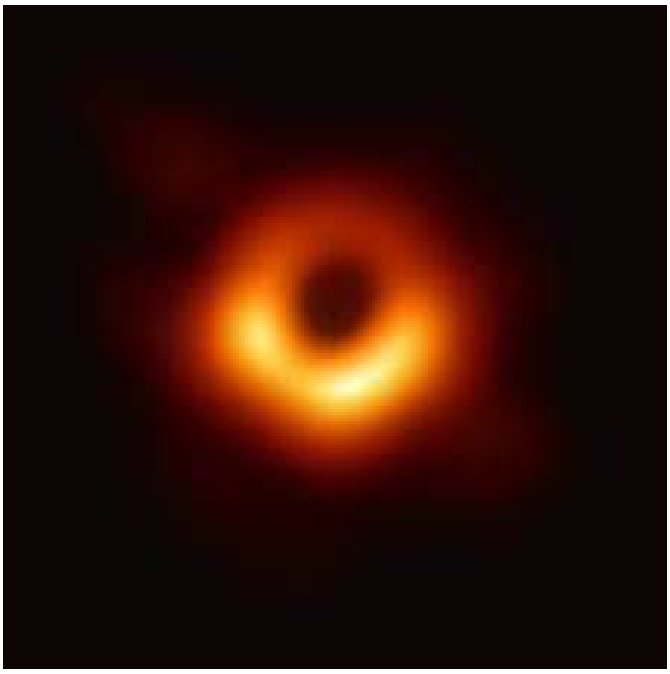
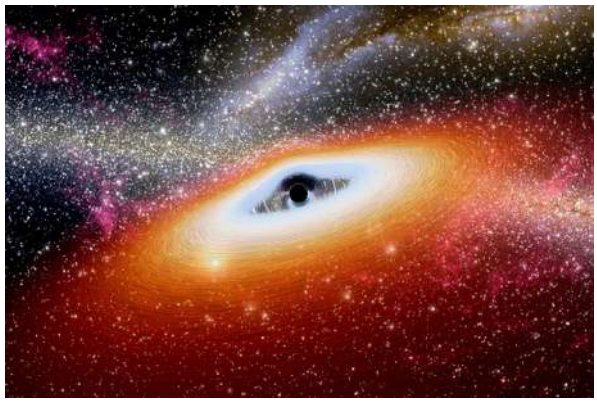


Fig 3: *Image of M-87*



SPACETIME & GRAVITATIONAL STRUCTURES

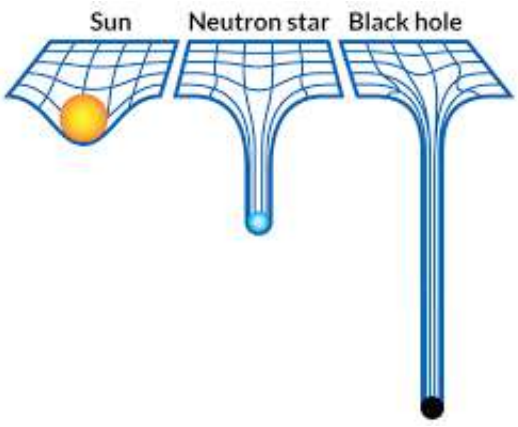


Fig 4: *Gravity warping spacetime for different masses*

Before delving into the theory of black holes, we must understand what "Spacetime" is.

The primary theoretical proposal about black holes originated from Einstein's theory of General Relativity. Oversimplified, it states that gravity is the curvature(bending) of spacetime. An object which is denser will have a larger curvature in spacetime(DoS, 2021). Therefore, the more curved spacetime is, the stronger the gravitational force is. Let's have a closer look into the detailed structures of a black hole.

"ANATOMY" OF A BLACK HOLE

All black holes follow the same principle structure. Almost all of the black hole's mass is condensed into a point called the Singularity, where density becomes infinite. This property distorts and curves spacetime infinitely as well. Surrounding the singularity, is a theoretical region called the event horizon. The Event Horizon is an area of which nothing, even light, can escape. In fancier words, the escape velocity in the event horizon for any given object exceeds the speed of light (COSMOS, n.d). Therefore, once an object enters, it would be impossible to escape as no mass can be faster than light. (Stardate, n.d)

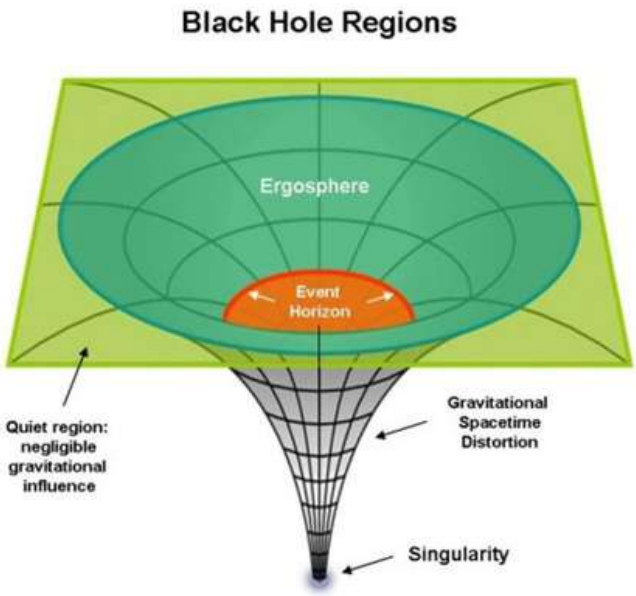


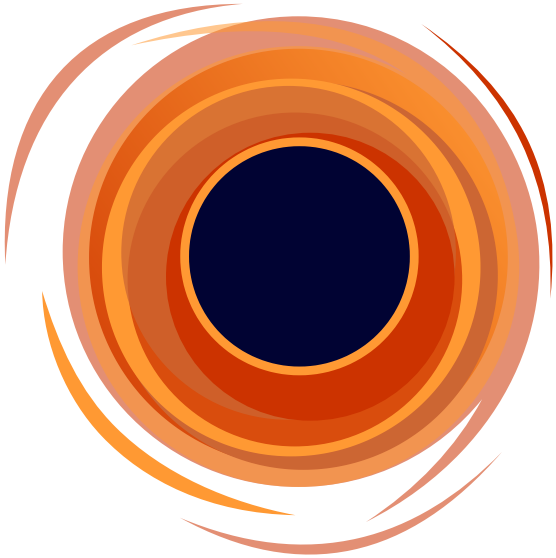
Fig 5: *Regions of a Black Hole*

$$R = \frac{2GM}{C^2}$$

Fig 6: *Schwarzschild Radius*

A way of measuring the Event Horizon is through Schwarzschild radii. This unit is defined as the distance between the centre of a black hole to the edge of the event horizon. The area of the event horizon depends on the size of the black hole itself(Britannica, 2021). For example, the supermassive black hole at the centre of our galaxy, Sagittarius A*, has an event horizon diameter of 7.9 million miles(College, 2021). Whereas, if our sun were compressed into a black hole, its diameter would only be 3.62 miles wide(Wikipedia, 2021).

The ergosphere is a region where spacetime is still heavily deformed, located at the outer event horizon. In this area, escape is still possible but incredibly high speeds would be required to overcome the gravitational pull. An example affected by this property is the photon sphere where the gravity around a black hole is so strong that it causes light to orbit. For a black hole, the photon sphere lies at 1.5 Schwarzschild radii(Hamilton, 2006).



CONCLUSION

In more recent news, the James Webb Space Telescope alongside the Event Horizon Telescopes have a mission in plan. One to finally reveal the appearance of the black hole in the centre of our galaxy, Sagittarius A*.

To conclude, studying black holes is a field that is not only fantastically interesting and developmental, but it also serves of great importance to physics and our understanding of the universe. As put by Sera Mankoff, NASA(2021), “Black Holes are just cool. they are the most extreme environments in the known universe, where we can put our fundamental theories, like general relativity, to a practical test”.

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