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Insignificance

Nirmit Jobanputra discusses how insignificant we are in comparison to the scale of our universe

The Antikythera Mechanism

Eleanor Jones takes a look at the world's earliest computer

Advances in Space Exploration in the Past Decade

Aaditya Manjith explores how far we have come

Magnetic Fields

Ali Khan discusses the Earth's magnetic field, the ongoing shift in the magnetic poles and its impact on future society

Welcome Back!

Edition 11, Lent 2021

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A Note From The YSJ Team

After a hectic term it's been great to have so much participation in the journal. For this edition we've had articles from all ranges, lower, middle and upper school which is incredible. It's amazing to see that there is so much enthusiasm around science and as a team we've loved reading the articles as they have come in. We are really excited to bring this edition to you and hope you enjoy reading it as much as we have creating it!

Cover Images

"Dynamic Earth - Earth's Magnetic Field" by NASA Goddard Photo and Video

"Speeding Clouds at the Milky Way" by lrargerich

Contributions

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The Antikythera Mechanism

Eleanor Jones

What is the Antikythera Mechanism?

Figure 1: Computer image of the Antikythera Mechanism showing front dial (left), exploded gears and back dials (right)

Often described as the world's earliest analogue computer, the Antikythera Mechanism is a mechanical device used by the Ancient Greeks to predict the movements of the Sun, Moon and the five planets known in antiquity. It was discovered by sponge divers in 1901 in a Roman shipwreck near the Greek island of Antikythera. However, since only a third of the mechanism remains, split into 82 corroded fragments, how it actually works has long been, and remains, a mystery. Despite this, researchers at UCL have used a range of methods to examine the remaining

fragments and have come up with a

Figure 3: Fragments of the Antikythera Mechanism

possible model of how it works.

What did we know already?

The mechanism was originally inside a one-foot-tall wooden box, with dials on the front and back. Past research has shown that the five dials on the back enabled the prediction of solar eclipses, as well as determining the dates of

important athletic contests, such as the Olympic Games.

Remaining fragments of the inscriptions found on the front and back of the mechanism give clues as to what the front dial may have shown. Although they are very corroded, microfocus X-ray Computed Tomography has made it possible to read the fragments of these inscriptions. The inscription on the back describes the front dial as a 'planetarium', with planets marked by 'little spheres'.

Earlier models of the front dial either do not work mechanically or over-simplify the orbits of the planets. Many use pointers to show the position of the planets, which leads to parallax problems, as they would involve nine pointers stacked on top of each other.

Figure 2: Earlier model using pointers to show positions of the planets

What does the new research suggest?

Figure 1: Computer image of new model for front dial

Similar to previous models, the new research suggests that the front dial shows a geocentric model (in which everything orbits the Earth) of the universe. In the new model, the Earth is represented by a gold dome in the centre. The black and white sphere orbiting it represents the Moon (and shows its phase), and the pointer shows the zodiac sign. The dials represent (from the centre) the orbits of Mercury, Venus, the Sun, Mars, Jupiter, Saturn, and the date, then the dials showing the signs of the Zodiac, then the Egyptian Calendar.

There is also a pointer known as the 'Dragon Hand', which shows the nodes of the Moon: these are where, in the geocentric model of the universe, the Moon crosses the Sun's apparent path. Although there is no evidence for this pointer in the inscriptions, it has been included as the lunar nodes are used to calculate eclipses and it is often included in later astronomical clocks. Also, it fits neatly with the rest of the mechanism: the gear visible on one of the fragments has four spokes, suggesting four mechanisms were attached to it. Three of these are the mechanisms for the Sun, Venus, and Mercury. The position and number of teeth on the gears means that the mechanism for the 'Dragon Hand' pointer is in exactly the right place when put on this fourth spoke. The rotation from these gears each turn one of many concentric tubes, which then turn the concentric rings on the front dial.

Figure 4: Remains of the large gear with four spokes visible.

When seen from Earth, the planets move backwards and forwards against the stars. This means a combination of gears and followers must be used to mimic this motion. Babylonian astronomy used cycles based on the position of the planet relative to the sun (synodic cycles) to predict the movement of the planets, for example, for Venus, there are around 5 synodic cycles in 8 years. Inscriptions on the front of the mechanism reference synodic cycles, and so in the new model, these 'period relations' are used in the gears to allow the model to show this backward and forwards motion.

What is the significance of the Antikythera Mechanism?

The Antikythera Mechanism is an astonishing artefact: it is estimated to date from between 150 and 100 BC, meaning it predates any other clockwork mechanism of similar complexity that we have discovered by over a millennium, and yet the skill involved in creating and building it is remarkable by any standard. Evidence suggests that other similar mechanisms existed, for example in his *De Re Republica,* Cicero, a Roman lawyer and politician, describes a similar mechanism built by Archimedes (c. 287–212 BC), and in his *De Natura Deorum* he describes one built by Posidonios of Apamea (c. 135–51 BC). Despite this, the Antikythera Mechanism is the only mechanism which we have available to study, meaning it is a unique insight into Ancient Greek mathematical and engineering abilities, as well as both Ancient Greek and Ancient Babylonian understanding of the universe.

Article continues on next page

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Considering the Influence of Genes on Who We Are

Kate Bailey

A widely known biological debate is the debate of nature vs nurture on what makes us human. Francis Galton coined the phrase nature versus nurture in the 1800s, he was the father of the eugenics movement who said that genes made us who we are. He was the cousin of Charles Darwin so to him the idea that intelligence can be inherited was definitely a positive. He believed in nature, genes and inheritance (Origins, 2011).

Nurture refers to environmental factors that could impact our development. This is whether are parents are supportive, what school we go to etc. This gives the idea that who we are is learnt entirely from our birth.

Plato and the Rationalists who argue knowledge is innate. They talk about the Socratic Experiment when an 'uneducated' slave boy did maths. Many people believe they should take this with a pinch of salt and that this happened with a healthy dose of Socratic teaching. Descartes (17th century) talks about a treasure house of innate ideas and understanding.

Aristotle, Plato's student who founded Empiricism which says knowledge is based on experiences. John Locke (17th century) talks about an empty cabinet and the phrase 'a blank slate' was a common description.

However in the 18th century Kant changed the game from innate vs. learnt to what exactly is innate. Kant came up with the idea that you couldn't learn without some innate concepts such as time, causality, and space. Kant then insisted that specific knowledge is acquired via experience. Kant showed Locke's cabinet with a bit more innate machinery. To bring this back to the Socratic experiment; Kant brought the idea that the boy's ability to learn was innate but his ability to do maths was due to his Socratic coaching rather than his genes. (Prinz, 2013)

This shows that it is not as simple as nature or nurture, as Kant began to argue. Instead it is a mixture. It is nature via nurture as Matt Ridley said, and highlighted that it is no longer one or the other but the extent to which each impacts (Ridley, 2003). This is reinforced by Donald Hebb a psychologist who, when asked, which contributes more to personality, nature or nurture, he answered, *"Which contributes more to the area of a rectangle, its length or its width?"*.

One way that we can see the impact of each factor is by using twin studies. By looking at the different between inheritance of monozygotic (identical) and dizygotic (non-identical) twins. As monozygotic twins have exactly the same DNA and are raised in the same environment but dizygotic have 50% the same DNA, but are raised in the same environment, the change in characteristics can be measured to show how much/if a characteristic is genetically inherited. One example is the use of twin studies in OCD to see if it was genetically inherited. It was found that concordance rate (ie both twins having

OCD) for monozygotic twins was 65-80% (Rasmussen & Tsuang, 1986) and that first degree relatives of someone with OCD had an 9% increased chance than those without (Nestadt, et al., 2000).
These all show that the instead of one or the other they both work through each other – both nature and nurture are needed for us to be who we are. So as we are no longer debating which we are now debating how much. Newer terms are emerging such as the idea of genetic pre-dispositions that are triggered by environmental stressors, combing both nature and nurture.

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Insignificance

Nirmit Jobanputra

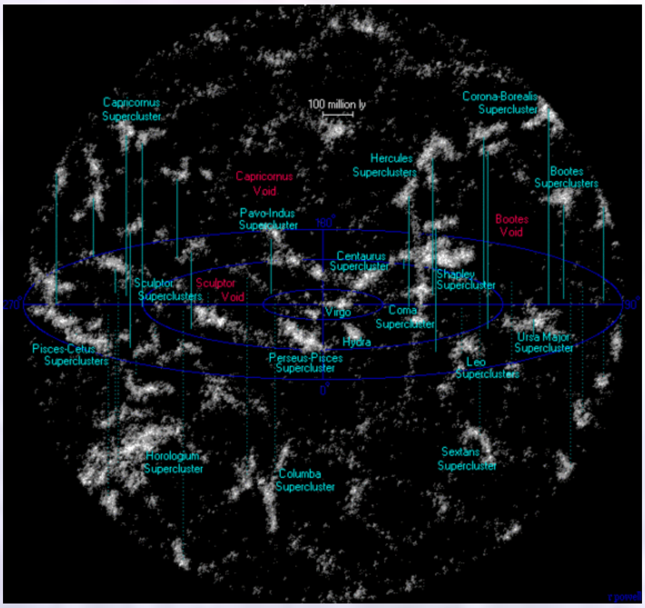
Before I begin I have inserted a quote by one of the greatest Astronomers and Physicists of all time Carl Sagan. It will give some perspective about what I am going to talk about:
"Look again at that dot. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. The aggregate of our joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child, inventor and explorer, every corrupt politician, every saint and sinner in the history of our species lived there--on a mote of dust suspended in a sunbeam."

Something we as humans struggle to comprehend and accept is how insignificant our planet and our species is in relation to the universe, we live in. The two best ways to measure our insignificance is via distances and time. Our journey begins in the Centre of our Solar system at the Sun. In our heads, we fall into the trap of thinking that our Solar System only extends to the outermost dwarf planets like Pluto. The truth is our Solar System is humongous as it extends all the way to the edge of the Oort Cloud. In fact, most of our Solar system consists of the Oort Cloud and the area around and between the planets is only a small part of the whole Solar system. Voyager 1 which was launched in 1977 is the farthest human object from Earth. It currently is travelling at 1 million miles each day however it has only managed to reach the beginning of the interstellar space. It is going to take another 300 years for Voyager to get to the start of the Oort Cloud and a further 30,000 years to get to the edge of our Solar system. To measure this distance from the Sun to the edge of the Solar System the unit we measure distance changes to light-years(1 light year=6 trillion miles). From our Sun to the edge of the Solar system, there is a distance of 1.57 light-years. This means that just to get out of our corner of our own galaxy Voyager 1 will have to travel a distance of over 9.8 Trillion miles.

Once we leave our solar system there is still another few trillion miles before we reach our nearest star, Proxima Centauri. This star is 4.35 light-years from Earth and can be seen very clearly in the night sky, however, in terms of regular distances (Miles) it is mind-boggling how far it is from us. To surprise people, one of the most famous stars, Polaris (The North Star) which has been used for Navigation for hundreds of years, is 430 light-years away from our Solar System. This means that when we look at the North Star at night we are looking at an object 2580 Trillion miles away. This object which has played such a key role in the development of humanity, and was seen as a "friend" of sailors, is in reality so detached and distant from us.
The fun begins when we move to the galaxy level. The radius of the Milky Way is estimated to be around 52,000 light-years and the Solar system is said to be somewhere in between the Centre of the Galaxy and the edge of it. Therefore, if

we travel around 26,000 light-years outwards from our solar system we will get to the edge of our galaxy. If we were to look down at the galaxy from this spot we would see the four spiral arms of the galaxy and within these arms lies tens of billions of stars, some bigger and some smaller than our own Sun. There would also be billions of planets in each one of these arms. In total across the whole Milky Way Galaxy NASA says there are between 100-400 Billion stars. There are so many Stars that NASA says we will never get a true value for the number of stars in our Galaxy as we will always be finding new stars.

The nearest major galaxy to our own is the Andromeda Galaxy which is 2.5 million light-years from us and is also set to collide with our galaxy in 4 billion years. The Milky Way and the Andromeda Galaxy are part of a cluster of 36 galaxies known as the Local Group. Our Local Group of galaxies has a whopping radius of 10 million light-years, a distance which our minds cannot even truly comprehend.



"Pisces Cetus Supercluster Complex" each grey area is a Supercluster containing on average 47,000 Galaxies.

The scale of the universe only continues to increase exponentially, and it is here when we can start using light-years as a time machine. The Local Group of Galaxies is part of a larger group of galaxies called the Virgo Supercluster. Within this supercluster exists at least a 100 Galaxy Clusters, some of whom are much bigger than our Local Group. The whole Virgo Supercluster has a diameter of 100 million light-years; however, some scientists estimate it could even extend further than this.

The Virgo Supercluster is part of an even larger structure which is called the "Pisces Cetus Supercluster Complex". This structure is 150 million light-years wide and 1 Billion light-years long. This huge structure is made of many different superclusters. The Pisces Cetus Supercluster complex is the final level of the universe's scale to an extent. At this level of size, there are a few other structures which are or similar size or bigger. For example, there is The Eridanus Super void and Sloan's Great Wall, which are positioned "next to" Pisces Cetus. The Eridanus Super void is a huge section of the Universe where there is a very low number of galaxies, however, it does not mean the area is empty. We are yet to know why and how this structure which is 1 billion light-years in diameter exists. Sloan's Great wall is more simply just a huge structure which is 1.5 Billion light-years in length and over 1 billion light-years from Earth. This structure is just a large wall of Galaxy Clusters. There are more structures at this scale of the Universe, and some might be many times the size of the ones we have discussed however scientists are still researching them and there is no clear information on these structures.

Finally, we get to the Universe size, which is an agglomeration of all these structures which are billions of light-years in size. We don’t know the exact size of the Universe now, because it is constantly expanding, and we can only see the furthest parts of our Universe from around 13 Billion years ago. As I alluded to earlier the finite speed of light means that the further, we look from Earth the further back in time we go. The Image is called the XDF(Extreme Deep Field) by Hubble. Each dot in the image is a Galaxy containing billions of stars. The image looked as far as 13.2 billion light-years into the Universe, which allowed Scientists to see Galaxies which existed 13 Billion

Years ago. These Galaxies now may no longer exist or have moved. However, observing these farthest Galaxies allows us to see parts of the Universe which are 13.2 Billion Years old and only 500 Million Years from the Big Bang. Furthermore, light from Galaxies which are 13.8 Billion light-years away are starting to reach Earth, which means that if we can focus on them we will be able to see the first Galaxies after the Big Bang and how the universe looked immediately after this event. Using the data from the furthest Galaxy’s and estimating the rate at which the universe is expanding, scientists from the University of Texas at Austin estimated the Universe is 93 Billion light-years in diameter. However, we are not even sure what the exact shape of the Universe is yet so this is a very rough estimate.

The final part of this journey is purely theoretical and philosophical, and that it is to do with the Multiverse Theory. This theory states that beyond our universe there are many more universes. There is no evidence for this theory yet however there is no major evidence which would suggest it is not possible, and the laws of Physics could potentially allow this theory to be true. For now, this theory has a more philosophical basis. If we look at history, when we discovered the Sun, we thought it was unique when we discovered our solar system we thought it was unique and no other similar systems existed, then when we discovered the Milky Way we thought no other Galaxy existed however there are millions of Galaxies, therefore based on historical experience it is most likely there is not just one universe, instead, there are many.

The Importance of knowing our scale:
Throughout this article, I have briefly gone through how small and insignificant we are to the size of the universe. This holds great scientific weight because knowing the basic structure and size of the Universe is pivotal to understanding the laws of it, however more importantly knowing our insignificance holds even greater in changing people's perception of life. Learning how small we are, encourages us to rethink the way we act and behave in many situations in life and prevents you from arguing over the smallest of things, Humans argue, fight and sulk over many things in life, which seem to be so significant however, in reality, they are so small in the grand scheme of things. This doesn’t mean you shouldn’t care about anything or anyone, however, the understanding of our insignificance can prevent so many minor disputes whether it be between people or countries. What I just said might seem a bit far fetched, however, it is a belief upheld by all the great Astronomers from Neil De Grasse Tyson to Carl Sagan who stated “It has been said that astronomy is a humbling and character-building

experience...for me, it helps underscore our responsibility to deal more kindly with one another and to preserve and cherish the pale blue dot"

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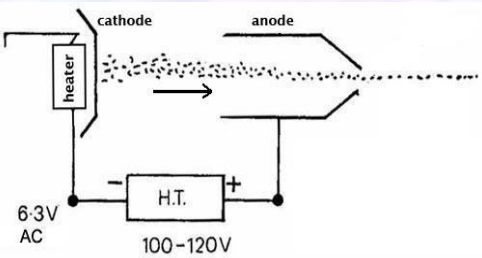
Everyday Particle Accelerators

Annabelle Onions

Many young physicists will have heard of particle accelerators such as the Large Hadron Collider (LHC) at CERN which is an enormous 27 kilometres long [1] but not many people understand how these devices work or if there is really any true use for them other than physics research. Sadly, many believe that particle accelerators are only useful for those interested in quarks and leptons and other particles that the general public has never heard of. These people couldn't be more wrong: these devices and the science behind them can pave the way to a greener planet and much more efficient production methods in a huge range of fields. They can benefit everyone not just those who research.
A particle accelerator is 'an apparatus for accelerating subatomic particles to high velocities by means of electric or electromagnetic fields' [2]. Clearly accelerators such as the LHC are part of this group but there is also a range of much smaller particle accelerators which are composed, in the most basic form, of a hot filament and voltage gradient [3]. A filament becomes hot and therefore emits electrons which are accelerated in a vacuum by a voltage and then focused with magnets (Figure 1). A beam which is

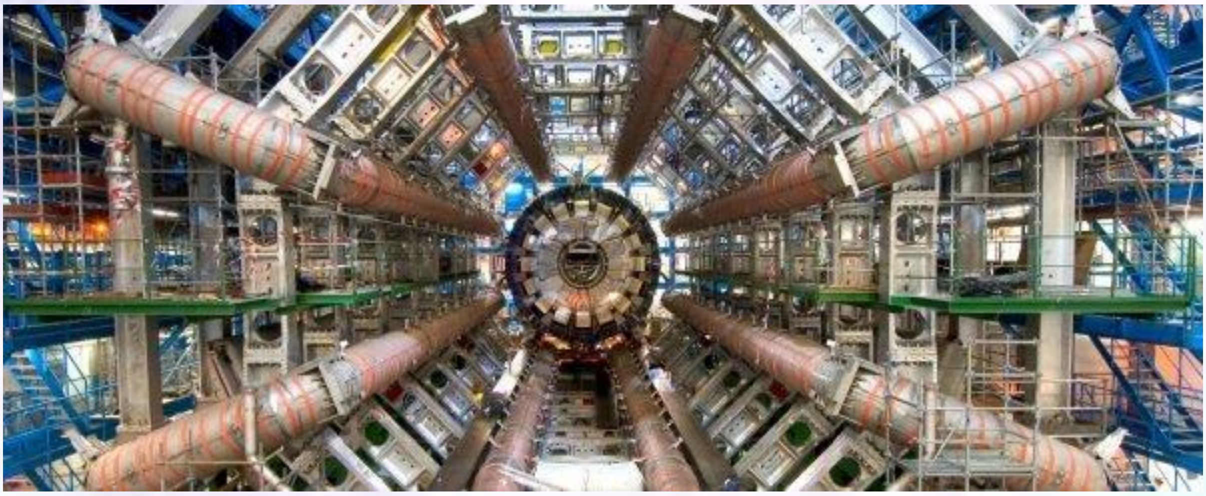
Figure 5-Taken from https://spark.iop.org/electron-guns#gref



equivalent of β radiation is created. This is otherwise called an electron beam. Thanks to how these accelerated electrons interact with matter, these beams have many uses, even beams which are classed as very low energy (beams with an energy less than 330keV) and low energy (energy between 330keV and 10MeV) [4]. These types of beams are actually the ones that are most useful to workforces and can optimize the countless manufacturing processes. More importantly, they can be created with a small, affordable accelerator.
One of the most interesting uses of the electron beam created by smaller particle accelerators is in food treatment [5, 6]. Every day, thousands of seeds and grains have to be treated to ensure that they are safe to eat and free from pathogens; this is often carried out using chemical processes which result in contaminated soil and can harm the biodiversity of the area. A very low electron beam carefully aimed at the surface of a seed is able to destroy the bacteria and harmful pathogens without affecting the chemical build of the seed or it's taste. This is thanks to the fact that the accelerated electrons ionize the atomic electrons in the DNA of the bacteria and water inside them causing molecular bonds in the organisms to break resulting in their death and a clean seed. The same principles can also be used to prevent rotting within other foods resulting in increased shelf-life and reduced food waste. Not only is the electron beam method much greener than a chemical method, it results in no harmful effects to the food or biodiversity of the area (which many chemical methods do).

It is the very same ionizing property of an electron beam which means that it can be used for sterilizing items such as tools within the medical profession, packaging for the food and pharmaceutical industry and within the electronics industry [7]. The strength of the penetrating power of an electron beam is limited by it's energy and the density of the material it is entering. This means that low energy beams are able to penetrate the top layers of packaging of very sensitive electronic items without affecting any circuits inside or limiting the usability of the item. The same principles can be applied to the packaging of sensitive medicines where using chemical methods sterilise is very risky to human health. Currently, within the medical industry, it is not possible to sterilise temperature sensitive surgical components without damaging their properties or functionality. This is most definitely a problem which could be potentially solved with particle accelerators and electron beams. Further research is required in this area as the low penetrating power of the beam restricts it's use but a much more sensitive system with very low energy rather than high energy beams (which are currently used) and smaller accelerators would hugely help the medical industry progress in terms of using this technology to sterilise surgical devices.

vacuum (to keep as much energy within the electron beam as possible and stop air particles interfering with it) and impurities can be removed from it due to differences in melting points. Electron beam welding is another little known process which hugely benefits workplaces as again, a very powerful beam is fired towards two pieces of metal in a vacuum and the heat produced cause the metals to join together[9, 10]. Also, when electrons interact with matter as a result of ionization (and excitement where an electron changes energy level within an atom) secondary electrons are produced which can be detected by a device called an electron microscope allowing a manufacturer to create an image of the weld. This means that the welding can be inspected as it is being carried out which saves time and a huge amount of extra equipment. Both of these processes are essential to the metal industry in particular and are possible due to the use of a particle accelerator.



Electron beams also have uses in other industries as a beam of accelerated electrons contains a lot of kinetic energy. On impact with a solid this energy is transferred to thermal energy (heat) and this is a very useful property. One example of this is metal re-melting which is often carried out with an electron beam with a power density of around 10^6 W/cm^2 [8]. The metal is melted in a

Increasing the energy of a very low electron beam only slightly to make it just a low energy electron beam (rather than one with very low energy) opens yet another host of uses for accelerator technology. These beams can actually modify polymers due to their ionization properties meaning that they are often at work in unexpected places. Particle accelerators and electron beams have been sealing crisp packets since around the 1980s [6] and even have the ability to turn a colourless gemstone into a blue one (if used in conjunction with other processes) [11]. A more technical use is within semiconductor modification in which low energy electron beams are able to optimize the switching characteristics (part of a component that allows it to act as a switch) for use in hybrid cars thus improving the efficiency of the car, something which is key in successful manufacturing.

Low energy beams also have multiple uses which help to make systems much more environmentally friendly [12, 13]. Accelerators can be used to treat sewage by irradiating it and thus removing bacteria leaving it free to be used as fertilizer within the agricultural industry. The disinfected sewage could also help reduce chemical fertilisers by being used to grow some microbes such as *Rhizobium* and *Azotobacter* which are used in biofertilisers [14]. This is a method which has already been tested and had huge success in the Republic of Korea. Research is also focusing on methods of cleaning flue-gas with electron beams to reduce pollution as the accelerated electrons can break bonds and therefore remove pollutants which would otherwise remain in the air [6].

There are countless other uses of small particle accelerators. For example, in medical treatments and security including imaging vehicles which may be carrying weapons and putting in place counter-terrorist methods on borders. The scope of the particle accelerator is vast; they do not only belong to the world of physicists working on discoveries such as the Higgs boson. The field of nuclear physics is one that is applied and used in so many scenarios and impacts upon us every day. In her lecture [15], Dr. Suzie Sheehy, a researcher and particle physicist, revised the toast popular at JJ Thompson's Cavendish Laboratory in the early 1900s in saying "To the particle accelerator… May it be of use to everybody". It is clear that this technology is of use to the entire world. It is already in place and being used across a diverse range of industries. Nuclear physics unlocks an entire world of potential.

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Image Credit: CERN

History

The first surgical robot was introduced by Kwoh et al in 1985 with the purpose of performing neurological biopsies (a surgical procedure in which a thin needle is inserted into the brain to remove a small piece of tissue to examine under a microscope). This was the Puma 560, the first of many similar master-slave surgical systems. The same system was used by Davies et al in 1988 to perform a transurethral prostate resection (a procedure involving cutting away a small section of the prostate gland).
This was the predecessor of the later PROBOT, designed specifically for transurethral prostate resections, and the ROBODOC, which was the first surgical robot to be FDA approved with the specific purpose of coring out the femur during hip replacements. During the 1980s, the idea of telepresence surgery (surgery performed using a robot without the surgeon being physically present) took the interest of virtual reality researchers and became a great incentive for research into further development of such robots.

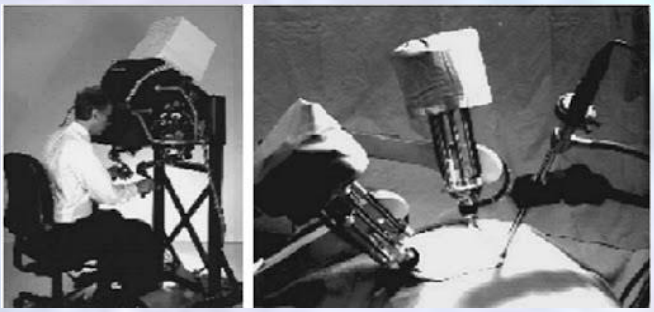

Figure 6: A surgeon at a console controlling the Puma 560

This led to a team from the Stanford Research Institute and NASA developed a telepresence system to be used in hand surgery, with the main design goal being to give the surgeon a sense of directly operating on the patient while still overcoming the limitations of doing so. The US Army, realising the possible benefits of telepresence surgery devised a system in which a wounded soldier was loaded onto a vehicle containing robotic surgical equipment, where he would be operated on by a surgeon based in a nearby mobile advanced surgical hospital (MASH). This system hoped to decrease wartime mortality rates by preventing wounded soldiers from bleeding out during the time required to transport them to a facility with sufficient medical equipment.

The next development in robotic surgery was in 1996, when Computer Motion Inc. produced the Automated Endoscopic System for Optimal Positioning (AESOP), a robotic arm controlled by surgeon's voice commands to manipulate an endoscopic camera.

Currently, many surgical robots are being researched. Shurr et al have developed a master- slave manipulator system for minimally invasive surgery called ARTEMIS, which consists of two robotic arms and a control console (i.e. a robot controlled by the surgeon which allows perception of contact between the robotic arms and soft tissue while operating remotely).
Dario et al have developed a prototype miniature robotic system used in computer enhanced colonoscopies. This provides the same functions as a conventional colonoscopy system but does so using an inchworm like locomotion using vacuum suction inside the colon. This is teleoperated by a surgeon and eliminates the need for manual endoscopies, also allowing more control of what is visible.

Current Systems

Currently, several surgical systems have been approved by the US Food and Drug Administration and are in use for some procedures, e.g. the AESOP, the ROBODOC, and most notably the Zeus and Da Vinci systems which are used in a variety of different procedures involving laparoscopies. The Da Vinci system, developed from US Army surgical robots, consists of three main components: A visual cart holding a dual light source and three dual chip cameras, a master console where the surgeon operates the robot, and the main moveable cart onto which two robotic arms and a camera arm is mounted. This camera arm contains dual cameras which work together to produce a 3D image of the surgical site, displayed on the master console's image processing computer. The master console also holds foot pedals which work to control electrocautery(the technique of burning a part of the body to remove or close off part of it, destroying some tissue to mitigate bleeding/ damage and remove an undesired growth or minimise other potential medica harm such as infections when antibiotics are unavailable, using an electrically heated needle), a camera focus, and control grips which manipulate the robotic arms. These provide 7 degrees of freedom, a huge improvement on much more restrictive and less dextrous manual surgery. The image from the camera arm is displayed just in front of the surgeon, therefore giving the illusion that the surgical instruments are extensions of the control grips, replicating being physically present at the surgical site (see fig.2).

Advantages:

Dexterity-Seven degrees of movement compared to just four in manual surgery means surgeons can control and manipulate tissue much more easily and can do so avoiding the dangers of unintentional tissue damage due to hand tremors.

Eliminates fulcrum effect- In manual laparoscopies, the end of the tool moves in the opposite direction to the surgeon's hand's (the fulcrum effect). This causes a steep learning curve due to the unnatural and counter intuitive nature of the procedure. Surgical robot systems account and adjust for this, eliminating the fulcrum effect.

Better visual feedback- The visual feedback given by tradition laparoscopic cameras is a 2D image which does not effectively convey distances/shapes. The camera in a robotic system e.g. the Da Vinci system generates a 3D image conductive to a much more accurate replication of anatomical structures. The image can also be controlled to a much greater degree, e.g. movement and magnification.

Figure 7: The Da Vinci system

Better physical feedback- During manual laparoscopies, there is a greatly reduced sense of touch, meaning tissue manipulation is heavily dependent on visual feedback. Robotic systems can provide haptic(physical) feedback which further decreases chances of unintentional tissue damage.

Microsurgery- The use of robotic systems could make microsurgery much easier, as they allow large movements of the surgeons hand on the control grips to be scaled down to microscopic movements of the surgical instruments, greatly increasing a surgeon’s capabilities to correctly identify and dissect tissues/ to perform microanastomeses(surgical connection between two anatomical structures at a much smaller level).

Disadvantages

Unestablished- As robotic surgery is a relatively recent advancement in terms of medicine overall, there have not been enough procedures or long term follow ups to confirm robotic surgery as an effectively replacement to conventional surgery. Even if it were to be established as such, many surgical procedures would require a complete redesign for the robotic system to be effective in practice

Cost- Most surgical robots cost around $1,000,000, which makes them almost completely impossible to fund on a large scale, especially in economically weaker areas. This alone presents a difficult dilemma: While some argue that for surgical robots to be worth the cost and possibly decrease it they need to be put into widespread use, others argue that in the long term they will never be worth the cost due to constant upgrades and technological developments in the field which could further increase the price.

Size- Robotic systems are relatively large in terms of current operating theatres, as well as the surgeon. Nurses, and the control console this could lead to a need for larger operating rooms to accommodate for this. Further increasing the cost to hospitals/ governments.

Overall, early data shows that although the use of robotic systems is feasible, more clinical trials are needed to gain enough information to decidedly say whether or not they are a worthwhile alternative to conventional surgery. However, surgical robots have undoubtedly expanded what was previously thought to be the boundaries of minimally invasive surgery and have huge potential for further development in the future.

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The History and Evolution of Life on Earth

Dhilan Bulsara

It is one of the most intriguing questions, yet very challenging: how was life created on earth? Today, humans (Homo sapiens) are recognised as being complex organisms that evolved from apes around 6 million years ago, but we also know that life began approximately 3.7 billion years ago, so how did this curious scientific event occur?

At a time when there was no oxygen gas in the atmosphere, organic compounds, particularly carbon and biomolecules, were found in rocks that are around 3.7 billion years old. Scientists believe these carbon molecules are a sign of life, as they were produced by microscopic organisms. These microscopic organisms are believed to originate from RNA (ribonucleic acid) and proteins, both essential macromolecules for all forms of life. At this early age when methane dominated the atmosphere, oxygen atoms were only located in compounds such as water. Fossils of single-celled organisms, believed to originate from 3.5 billion years ago, provide scientists a key starting point to the creation of life when living cells made energy primarily out of sulfur.

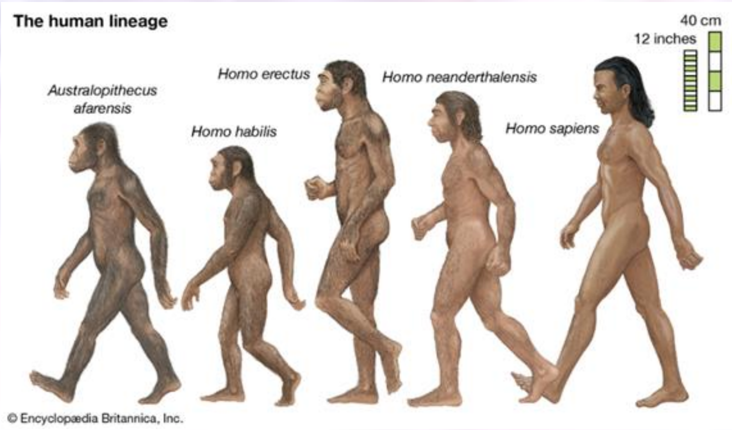
Oxygen, a gas considered to be essential for life today, only started building up in the atmosphere in the late years of the Archean Eon, about 2.4 billion years ago. Cyanobacteria became the first living organisms to photosynthesize, producing food (glucose) and oxygen from water and light. Around 2 billion years ago, microbes did not have specialised cells or organelles to perform specific jobs, however, microbes began to live inside other microscopic organisms. These microbes acted as organelles, which together supported the whole of the eukaryotic cell. This was the starting point for cells working together to survive. Around 800 million years ago, cells that lived together became animals, specifically ocean sponges. Evidence from DNA suggests that these sponges could survive in an atmosphere consisting of only 4% of oxygen because they were inactive seawater creatures.

Picture 1: Oldest Fossil Evidence for Animals Found | Live Science

Evolution occurred rapidly after the formation of sponges which helped raise the oxygen levels in the atmosphere. Around 600 million years ago, marine life included ctenophores (comb jellies) and organisms with bilateral symmetry. Cnidarians, including jellyfish, corals, and sea anemones began to appear just after the formation of sponges. The Cambrian explosion, beginning around 535 million years ago, was a historical event when metazoan phyla (including sponges and worms) started to appear on fossils over a short time. Soon after, conodonts, including hagfish and eels, appeared on fossils around 500 million years ago.

All life up to this point was in the oceans of the earth, so why did life begin on land and how did it happen? Fossils show that around 500 million years ago, animals started to explore the land of the earth. This quickly resulted in the birth of the Great Ordovician Biodiversification Event, allowing

evolution to increase the diversity on land, creating plants and land animals. Over time, plants such as liverworts began to dominate the land on earth, whereas, in the oceans, fish split into two main groups: bony fish and fish with cartilage.
400 million years ago, scientists believe that insects, four-legged animals, and trees existed on earth's land. These four-legged animals were called tetrapods which were common ancestors to amphibians, mammals, and reptiles. Over the next 100 million years, amphibians and reptiles (including birds) evolved from the tetrapods, during a time when the atmosphere was rich in oxygen gas. Around 300 million years ago, sauropsids evolved from tetrapods. Sauropsids had features of modern reptiles and later evolved into dinosaurs around 250 million years ago. Dinosaurs began to dominate the land at the end of the Triassic period before endothermic (warm-blooded) animals came to evolve. During the Jurassic period, plants began to flower and grasses evolved. Then, approximately 66 million years ago, 75% of all species on earth became extinct, including dinosaurs, due to the Cretaceous-Tertiary extinction event. Scientists today believe that primates (lemurs, monkeys, and apes) existed approximately 60 million years ago, allowing monkeys and apes to evolve around 40 million and 25 million years ago respectively. Gorillas, chimpanzees, and bonobos branched off from apes approximately 7 million years ago, allowing Australopithecus (southern apes) to diverge from chimpanzees. Around 2.5 million years ago, Homo habilis (a species of human and part of the homo group) existed and is believed to be evolved from the Australopithecus in Eastern and Southern Africa. Homo erectus (meaning "upright man") is believed to be an early human dating back to approximately 1.8 million years ago. Homo erectus is known to be a hunter-gatherer. They extended their population from Southern Africa to modern-day east Asia and they had a brain size of 1000cm^3 (1.6 times bigger than the brain size of Homo habilis). Homo neanderthalensis (extinct species of humans) are believed to have first appeared in Europe and the Middle East around 230,000 years ago. Homo sapiens ("wise man") is the species to which all modern human beings belong and is the only species part of the Homo group which is not extinct. They are believed to originate in Ethiopia roughly 200,000 years ago and have a brain size of over 1.3 times the size of Homo erectus.



Picture 2: Human evolution - The emergence of Homo sapiens | Britannica

In the future, modern-day humans may not exist. Homo sapiens could evolve into something taller, wider, or smaller. Maybe living organisms will need to resist the rising temperatures on earth, or follow the pattern of the homo group and develop larger brains, or will artificial intelligence take over and become more intelligent than humans? Evolution is hard to predict but remains very fascinating today.

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Advances in Space Exploration in the Past Decade

Aaditya Manjith

Introduction

For generations we humans have looked up to the stars and wondered what awaits us beyond the confines of our own little blue planet. But though we have been looking up there for a long time, it was only in the last 60 years that humanity has actually answered the call to explore. On the 20th of July 1969, Neil Armstrong and Buzz Aldrin landed on the lunar surface for the first time in human history. After this pinnacle, we have taken many strides to go on to the next frontiers that will prove to be milestones in humanity's journey. This article aims to spotlight the most recent advances in this field of study.

Recent Discoveries

When talking about discoveries, it is always hard as there are new stars and galaxies found so often. So instead, I will be bringing to you the most notable discoveries of the last decade. In 2011, NASA's Messenger probe became the first man made probe to orbit Mercury. [1] On the 6th of August 2012, the Curiosity rover reached the surface of Mars and made contact back with Earth. [1] Later that same month, NASA's Voyager 1 probe left the outskirts of our solar system to become the first probe in interstellar space. [1] The next big leap for humankind was when the New Horizons spacecraft became the first spacecraft to study Pluto in full depth and orbit it. [1] In April 2019 a group of scientists led by MIT graduate Katie Bouman took a full colour photograph of a black hole. This great feat was achieved by having eight massive telescopes pointed at the same point in space. This was effectively named as an 'earth-sized telescope'. [2] The year of 2020 was all about Betelgeuse. This supersized star started dimming in late 2019 and carried on in 2020 leading astronomers to think it was about to explode. But the NASA's Hubble space telescope helped astronomers to conclude that the star has only ejected some of its material. [3] The year 2021 provided all the luck of the new year with NASA's James Webb Space Telescope (which is the much more sensitive successor of Hubble) sending back its first images. This year also had NASA's Perseverance Rover landing on Mars on the 18th of February 2021 at 20:55 GMT with the Ingenuity helicopter becoming the first aircraft to fly on another planet. Other countries have not been far behind, with India's Mangalyaan mission reaching Mars orbit in 2014, China's Tianwen-1 reaching Mars orbit this year and the UAE's Hope probe set for Mars. [4], [5] So this year may yet indeed be the year of ground-breaking discoveries on Mars. [6] As well as this, there is NASA's Artemis program to land the first woman and next man on the moon. The new year does indeed give new hope.

Latest Technologies

One of the latest new technology to use now is 3D printing. This is a way of making models out of any chosen material. This can revolutionise the space industry as we can use these to build whole structures in space itself instead of assembling it on the ground and wondering whether it will survive launch. [7] As well as this we also have new rocket boosters that are completely reusable that were made by the private company SpaceX. Instead of just crashing in the sea like previous NASA missions, these boosters can land upright on a landing pad that is reserved for them. [8] The Perseverance rover mentioned above has also got some stunning new technologies used for the first time in space. Apart from an x-ray spectrometer1 state of the art science cameras (including the SHERLOCK and the WATSON!), a subsurface radar, a weather station and a laser micro imager, it also incorporates MOXIE – an experimental device to produce oxygen from the Martian CO_2. [9]

<u>Privatization of space exploration and tourism</u>

One main point to reckon is that now it is not just government space agencies but private space agencies too are working on deepening our insight on the universe. The first space agency to be fully private was not in fact SpaceX, as you may think, but it was Space Adventures. [10] This was a private tourism company founded by Eric C Anderson. Although this may have been the first private space company it certainly is not the most pioneering one as that title is held by Space X. It was founded by Elon Musk in 2002 and has made major accomplishments in just 18 years. It has launched humans to the international space station (ISS). It has recently also cooperated with NASA to launch many satellites into space as part of the Starlink operation, an operation to give Wi-Fi to the whole world. The rocket used for this is the Falcon 9 rocket. [11] All in all, SpaceX is a private company that is at the level to rival even the best government space agencies.

<u>Future missions</u>

One very well-known mission for the future is the NASA Artemis program to return to the moon and this is the pinnacle of innovation now. [12] The Artemis program has a new capsule called Orion. It will serve as the exploration vehicle that will carry the crew to space, provide emergency abort capability, sustain astronauts during their missions and provide safe re-entry from deep space return. [13] The other novel idea incorporated within the Artemis program is Gateway. This is an outpost that will orbit the moon much like the ISS now orbits the Earth. [14] This program will be vital as recently researchers have noted that in the craters of the moon there are large quantities of water ice. This can be then used to restock on supplies including water to drink, oxygen to breathe and hydrogen for fuel. [12] This will provide for missions to go from there to Mars and beyond.

<u>Conclusion</u>

This article was written to spotlight the breakthroughs over the last decade that have made the idea of humanity settling on another planet a very real possibility. And if we carry on making these breakthroughs then this could come true sooner than we think. This could provide us a viable final solution to global warming which is a very real threat to humanity's future on Earth. If all else fails, we could settle another planet and restart the human civilisation.

1 A spectrometer is a device which is used to probe a property of light as a function of its portion of the electromagnetic spectrum

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Image Credit: NASA

Leaving a Mark – Could Aeroplane Tyres Be an Opportunity for Aviation Sustainability?

Rabiah Ahmad

The elastic properties of the material rubber make it suitable to use for aeroplane tyres, which are designed to absorb much of the physical shock upon landing so that the experience is less jolting from the velocity and mass of the aircraft as it descends upon the runway. These properties also mean that rubber is unlikely to be replaced by another material due to the forces to which it has to be exposed for this purpose, despite the environmental detriment of its production and total life cycle, and the function means that the use of sealants could inhibit the role of friction as the vehicle comes to a stop.

As an aircraft hits the runway, the resulting friction and thermal energy transfer causes rubber to be deposited from the tyres on to the surface. The accumulation of this rubber can reduce the braking capability of an aircraft by decreasing the friction[1] between the landing tyres and the runway, and therefore airports are responsible for the cleaning and removal of this rubber periodically, largely depending on the frequency of landings and the volume of material deposited per landing based on aircraft type, to maintain safety. Common methods for removal include chemical techniques such as solvents that dissolve the material so it can be washed away easily, and mechanical techniques

on their own such as high-pressure water removal, or hot compressed air from gases being produced by a combustion chamber to burn the rubber deposits.[2] Each method has various advantages and drawbacks: chemical solvents require dilution and other precautions to minimise the risk of harm to the surrounding ecosystems and habitats; the depth of the rubber deposits can lower the effectiveness of high-pressure water, and hot compressed air can require high amounts of energy to generate – as well as create carbon deposits that require additional removal afterwards and may result in environmental contamination. The mechanical action of the hot air is thought to be unlikely to cause material breakdown of the runway, although caution is still required in case debris interference does occur with the aircraft and the environment.[3] Another consideration could be the preservation of the rubber: some of these methods may be likely to break down or disperse it, whereas research suggests there would be environmental and economic

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[3] International Civil Aviation Organisation,, *Airport Services Manual / Chapter 8 / Removal of Rubber*, https://skybrary.aero/bookshelf/books/4544.pdf accessed 2021

advantages to instead collecting the deposits and reusing them elsewhere.[4]

Before its application, the production process of the rubber alone has environmental costs too: natural rubber is derived from plants, making it a renewable resource but producing it requires high amounts of energy, chemicals and water, thus consuming fossil fuels and
polluting local ecosystems through the resulting products and the waste output.[5] It also struggles to meet increasing demands so synthetic rubber is another material used which also widely depends on the use of non-renewable fossil fuels for both material and energy production. Therefore, the potential for either repurposing or reusing the lost rubber could be beneficial in terms of resource consumption and ecological impact. Studies suggest that rubber collected from the runways, as well as from scrap tyres leftover from the aviation industry as a whole, is suitable for use in aggregates for constructive purposes, or as a component of biofuel production and combustion, and even in protective hard engineering management strategies such as retaining walls or frost insulation.[6] When combined in the right proportion, it is concluded that rubberising concrete is a particularly cost-effective solution for rubber waste and can withstand ample amounts of physical and atmospheric loading compared to typical concrete. Additionally, there is advice suggesting that the waste rubber powder from the tyres and their deposits should be used during wastewater treatment when removing toxic metals.[7] Compared to the disposal of carbon deposits as seen in the use of the mechanical compressed air removal techniques, this process poses a less wasteful or environmentally damaging answer to the maintenance of airport runways.

A special property of the rubber used in aeroplane tyres is its conductivity which prevents the static electricity – built up from the electron transfer which occurs due to the high amount of friction and energy transferred during landing – from expelling sparks which could cause electrical failure (as well as the risk of fire or explosion) within any of the numerous electrical components within the plane, by instead transferring it to the ground. Whilst rubber itself is naturally an insulator, it can be modified to give it these required properties by adding conductive substances (often metals in this case, that contain free electrons to enable the transfer of electrical energy – the flow of current). Due to the integrated nature of these material components, the recollected rubber from a runway may still have its

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conductive properties; regardless, the imperative safety requirements as well as the demand for durability (which is decreased after repeated landing impact[8]) means that either a significant volume of the reaccumulated deposits would be required for reuse within aircraft tyres, or otherwise different, lower-grade applications would be more appropriate for its use, as is usually the case with other more traditionally recycled materials.

Rather than reusing the rubber deposits released during aircraft landing in order to mitigate the environmental damage caused by the material's production, a more sustainable solution could be to replace its use with an alternative material altogether. Natural rubber comprises the majority of aircraft tyre production, but synthetic rubber is also used in supplement. The renewability of natural rubber means that it has sustainability potential but there are various limitations to this, due to economic and political factors related to the growing demand, market pricing, farming regulations and farmer income,[9] as well as the production expenditures mentioned previously. There has been research into various plant types producing rubber which could be sustainable alternatives to traditional methods as they produce minimal to no waste, stimulate biodiversity, minimise the use of chemicals that risk peripheral wildlife, and prevent crop competition or soil exhaustion by growing in ex-industrial areas of land that are generally agriculturally unsuitable: these plants could ideally displace the synthetic rubbers and their accompanying atmospheric emissions[10] which are being resorted to in light of the growing demands that outweigh the existing natural rubber availability, as well as the farmer instability due to the market volatility. Prominent examples of these sustainable rubber-yielding plants include guayule, which has now already been seen in tyre production,[10] and dandelion roots which too are seen in motor tyres and could further reduce the material's life cycle emissions within Europe especially as a result of proposals to grow them within close proximity to tyre production plants.[11] Should these materials be developed and tested to the correct level and found to be suited for aircraft tyres, they could eventually form an ideal solution to at least this sustainability challenge out of the many that exist within aviation.

Finding an absolute alternative could be beneficial but unfortunately, the specific properties of rubber and the comparable costs of various alternatives (both economically and environmentally) mean that this is yet to be implemented. Nonetheless, the viability of collecting rubber deposits from airport runways could be a promising insight into future sustainability by reducing resource consumption and increasing the operation of a circular economy in the interest of the environment. Where this

[8] Balderstone, P., Livadeas, A. and Wilson-Law, A., *Tyre Ageing*, 9th May 2019. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/808468/tyre-ageing-its-effect-on-material-properties-and-structural-integrity.pdf

[9] Lok, S. L., *What is sustainable rubber?*, 21st May 2019. https://www.eco-business.com/news/what-is-sustainable-rubber/

[10] Mehta, A., *Sustainable Rubber briefing: Sustainable rubber search hits the road*, 23rd August 2016. https://www.reutersevents.com/sustainability/sustainable-rubber-briefing-sustainable-rubber-search-hits-road

[11] Asda Tyres, *Sustainability is key to creating environmentally friendly tyres*, 4th May 2018. https://www.asdatyres.co.uk/blog/sustainable-tyres-environmentally-friendly-tyres-tyre-recycling/#:~:text=The%20rubber%20made%20from%20this,become%20mainstream%20is%20dandelion%20latex.

either cannot be applied or is in need of supplementation, the potential for new sustainable material options could prevent some of the environmental detriment which the current use of finite, emission-producing resources within existing methods causes.

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Image Credit: Getty Images

Nuclear Decay: The Key to Creation in the Universe

Caspian Eshtyaghi-Glass

On the morning of November 1st, 1952, four F-84 Thunderjets floated through the toxic dust of the blooming mushroom cloud, only an hour after 'Mike' (the first ever H-Bomb) had been detonated. However, the pilots were not assessing the monumental damage of this nuclear explosion as they attached filters to their fuel tanks, not cameras. They were risking their lives for the sake of a mere prediction; the prediction that a nuclear process, which occurred (and still occurs) in stars to create nearly all the matter that we know today, occurred in that one moment of mass devastation, creating something new: a new element (Chapman 2020).

The hypothesis happened to be correct and, in fact, element-99 and element-100 were discovered using the samples from the filters. This highlights one such aspect of nuclear physics that most people tend to overlook, with their minds clouded by horrifying images of Chernobyl and nuclear weapons. For, in nature, nuclear decay is primarily a means of creation, not destruction. Only in the last century have humans tried to recreate such creation on earth to uncover new elements, carrying on the elusive goals of alchemists (who had vainly tried to create gold from metals like lead).

Strictly, the creation of elements by means of nuclear reactions is called nucleosynthesis (as you will see, these reactions involve existing nuclei also). There are two main methods of nucleosynthesis that have been used in the recent past by humans. The first of these is neutron capture followed by beta decay, which was the process that occurred during 'Mike' as described in the introduction.

To understand how this method works it is necessary to grasp that our modern periodic table is ordered by number of protons (Z) and it is this number that characterises an element; to change a nucleus of one element into another, Z must be altered and nuclear decay, in the form of beta decay, is one way to do this (Herzberg 2020a). Beta decay entails the unstable nucleus releasing its internal energy by converting a neutron into a proton (and an electron — beta particle — is emitted to uphold conservation of charge), thereby increasing the number of protons by one (creating a new element). Figure 1 demonstrates this process with a carbon-14 nucleus becoming a nitrogen-14 nucleus (as its proton number increases from 6 to 7).

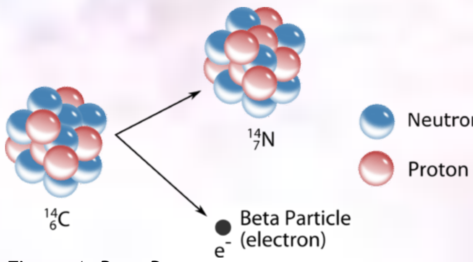


Figure 1: Beta Decay
Foundation, C.-12 (n.d.). Types of Radioactive Decay. [online] www.ck12.org. Available at: https://www.ck12.org/chemistry/types-of-radioactive-decay/lesson/Nuclear-Decay-Processes-CHEM/ [Accessed 15 Oct. 2020].

Although it is possible to convert elements into heavier ones using this nuclear decay (to increase Z), most naturally occurring elements have a half-life (the mean amount of time taken for half of the radionuclides present in a radioactive sample to decay (United States Nuclear Regulatory Commission 2020)) of billions of years and will not beta decay by themselves. Therefore, it is necessary to reduce the half-lives of these elements, using a process called neutron capture (Herzberg 2020b). This is when the nucleus is exposed to large number of neutrons and absorbs a certain amount of them (Physics World 2004a); these neutrons can be “provided by nuclear reactors and nuclear explosions ... and by supernova explosions” (V. I. Zagrebaev et al. 2011). By adding neutrons, a new isotope (atom of the same element with a different number of neutrons) is created with a shorter half-life meaning it will undergo beta decay more immediately. The reason behind this effect is that a higher number of neutrons (N) results in more unbalanced forces between nucleons (neutrons and protons), increasing the internal energy of the isotope, meaning it is more unstable (radioactive decay is an emission of internal energy after all, thereby with more internal energy a nucleus will undergo decay more readily).

New elements created in this way are termed transuranium, that is those elements which have an atomic number greater than 92 (that of uranium) and are mostly not found naturally on Earth due to their instability. Therefore, they are quite often synthesised through the neutron capture of uranium-238, the heaviest element (with most protons and neutrons) found naturally on Earth as it does have stable isotopes. This is exactly what happened in Mike’s explosion to create einsteinium (element number 99).

During this nuclear explosion, the uranium-238 atoms were bombarded with neutrons, with some nuclei capturing 15 neutrons (creating a “very ‘heavy’ uranium isotope” (Haire R.G. 2008)) stimulating seven successive beta decays (Redfern 2016), increasing Z by 7. This resulted in the creation of Einsteinium with Z=99 (as 92+7=99; 92 is the number of protons in a uranium nucleus).

Fermium, element-100, was also discovered in ‘Mike’, but in order to create elements with Z of over 100 (‘Superheavy Elements’) a new process, fusion, is needed as neutron capture is no longer a sufficient method (Herzberg 2020c); this is because the superheavy nuclei are so unstable (due to their unbalanced forces) that they decay before they can ‘capture the next neutron’ (Physics World 2004b). Fusion is the act of joining two smaller nuclei together at high velocities to create a larger nucleus. By doing this, the two proton numbers are added supplying the new nucleus with Z of over 100 (when using the correct starting nuclei), meaning this is the second successful method of nucleosynthesis.

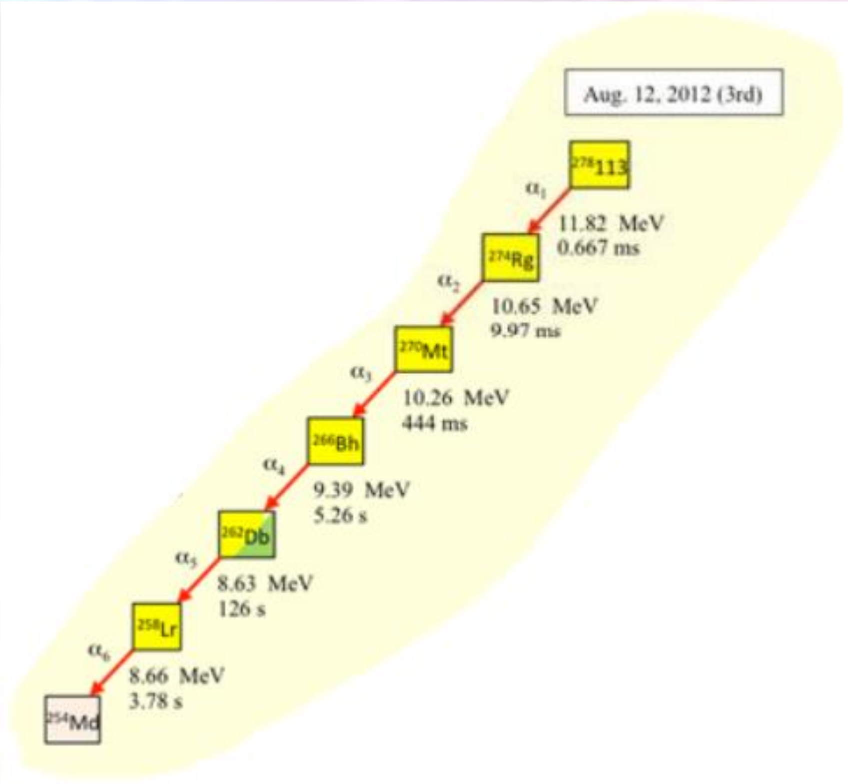
However, this new method poses two new problems. The first arises when trying to synthesise elements heavier than number 106. Such fusion of two heavy nuclei leaves the resultant superheavy nucleus in a highly “excited state” (Physics World 2004c) due to the high velocities — meaning it has gained energy. This excitation causes nuclei with more than 106 protons (as they are already so unstable) to immediately undergo fission, a type of nuclear decay in which the unstable nucleus releases its internal energy by splitting up into two smaller daughter-nuclei, essentially the opposite of fusion, hence undoing the creation (Figure 2 shows a simplified fission reaction). Something called cold-fusion resolves this issue allowing elements heavier than element-106 to be synthesised. This type of fusion involves “projectile ions that have a mass number of more than 40” being fired at the nuclei being used in the fusion reaction; the nuclei then absorb the kinetic energy of the projectiles meaning the resultant superheavy nucleus is a lot less excited (Physics World 2004d), solving the problem as it will now not immediately undergo fission.

Figure 2: Fission
Duke Energy (2013). Fission vs. Fusion – What's the Difference? [online] Duke Energy | Nuclear Information Center. Available at: https://nuclear.duke-energy.com/2013/01/30/fission-vs-fusion-whats-the-difference [Accessed 5 Oct. 2020].

The second challenge is proving that the new element has in fact been created when its half-life is so small that it exists for a fraction of a second. Interestingly, the alpha decay chain of the nucleus (a series of alpha decays ending with a significantly smaller ending nuclide than the starting nuclide) is used to confirm the element (Rodi Herzberg 2020c). Alpha decay entails the nucleus emitting 2 neutrons and 2 protons, an alpha particle (a helium nucleus); it is the energy of this emitted alpha particle that acts as a "fingerprint" of the decaying nucleus (Chan 2020). It is necessary to identify every transitory nucleus in the decay chain using this fingerprint, to prove that the newly created element existed. This method is exemplified in the creation of nihonium (element-113).

Nihonium was first synthesised in a cold-fusion reaction between bismuth-209 and zinc-70(35) (as their proton numbers add to 113) using the Japanese research group RIKEN's heavy-ion linear accelerator (linac). This is used to "accelerate" the nuclei "up to the required final energy" (CERN 2013); high energy is needed in fusion to overcome the electrostatic forces of repulsion between the protons in the two nuclei. Its existence however was finally confirmed in 2012 with a chain of six alpha decays, ending with medelevium-254 (Morita, K. 2016). Thus, the chain could be followed back, with every stage confirmed, to nihonium-278 (proving its existence). Figure 3 shows this decay chain with the energies of each alpha particle (used to identify the decaying nuclide it came from) measured in megaelectronvolts.

Figure 3: The alpha decay chain detected to prove nihonium's existence
Morita, K. (2017). The Discovery of Super-Heavy Element of Atomic Number Z = 113 Nihonium and Beyond. *Proceedings of the 14th International Symposium on Nuclei in the Cosmos*



(NIC2016).

It is easy to think that the act of creating these transuranium elements using these two processes is pointless (and even a waste of resources) if they only exist for a fraction of a second. However, they do have uses beyond being used as a base to synthesise heavier elements; for example, Californium-252 (element-98) can be used in isotope batteries as the heat energy produced by its radioactive decay can be transferred into electrical energy (Keller, C. 1976). Also, the aim to discover all possible elements is a scientifically rewarding process as new elements may improve our knowledge about stable elements. This is a possibility with Ununennium (element-119), which various groups of physicists are racing to discover (or rather prove its existence), as it will be an alkali metal (part of group 1). Therefore, it should follow group 1 trends (or will it?).

Regardless of these reasons on Earth, I cannot stress enough how important these processes are to the entire universe! They were (and still are) used in stars after the big bang to create all the elements we know today (apart from hydrogen) — with fusion being used to create elements up to iron, and neutron capture being used in supernovae explosions to create all the elements heavier than iron (Ridpath 2012). Hence, nuclear decay is by no means irrelevant, nor solely destructive, but is in fact the beating heart of creation in the universe. “And it’s breathtaking.” (Rovelli 2015)

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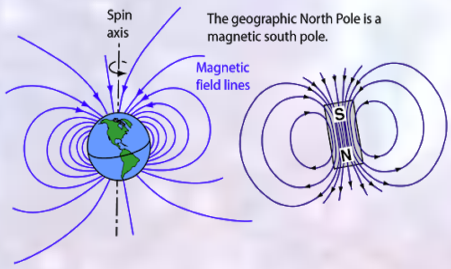
The Earth's Magnetic Field and the Pole Shift

Ali Khan

The Earth's magnetic field has a profound influence on modern civilisation today. From ship compasses to a standard GPS, satellite TV to mobile phones, much of the backbone of how we live our lives is only possible due to the magnetic field which blankets our planet. Furthermore, our very existence would be jeopardised without this phenomenon, as we would be exposed to fatal cosmic rays and radiation.
However, research suggests that the Earth's magnetic field has never always behaved in a uniform fashion, with multiple reversals of our magnetic 'poles' occurring gradually over the span of millions of years. The next shift is overdue (and has already begun); with so much of our modern technology fully dependant on the position of the magnetic poles the question arises: how will humanity cope?

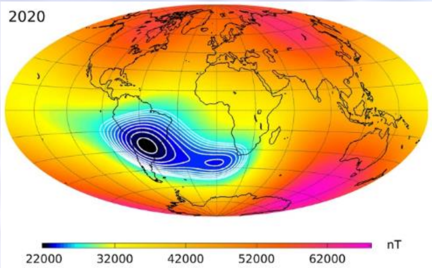
The Earth's Magnetic Field
The Earth's magnetic field has been active for millions of years – an integral part of the planet's normal functioning. It is created by the flowing of liquid metal in the outer core, which generates electric currents. Earth's rotation on its axis causes these currents to form a magnetic field, which covers and extends around the planet (Vejayan, 2017). The outer core, which is a region of molten iron alloys, flows in convection currents due to heat flow from the inner core, at around 5,730˚C. The Earth generates its magnetic field from this molten flow, in an effect which is known as a 'dynamo'. The magnetic field lines of the Earth take the shape of that of a bar magnet. Since, in a bar magnet, the magnetic field lines move from the magnetic south pole to the magnetic north pole, the Earth's magnetic south pole is geographically located in the north, and vice versa, as pictured.



The Earth's magnetic field protects the planet from 'solar wind' - a huge mass of charged particles which are released by the magnetic field of the Sun. These are often known as 'Coronal Mass Ejections' (CMEs), and contain dangerous radiation which would kill most planetary life and generate genetic mutations in species. Magnetic field lines act as a defence system, directing the stream of particles from CMEs towards the magnetic poles (Port, 2016). When this mass of charged particles enters the upper atmosphere near these magnetic poles, it collides with oxygen and nitrogen atoms. The energy from the CMEs is transferred into these atoms – making them glow causing light movement known as *aurora borealis* and *aurora australis*, dissipating all of the deadly radiation which would otherwise reach humans.

The South Atlantic Anomaly
The magnetic field lines of the Earth, though similar to a bar magnet, are not at all as structured or uniform. Over a large portion of South America, and along the south Atlantic Ocean, there is an unusually weak region in the magnetosphere. This allows particles from CMEs to move closer to the Earth than usual, which can have potentially serious ramifications. Although the true reasons for this magnetic anomaly are not comprehensively known or understood, it is believed that it was created largely due to a peculiar change in the motion of the liquid outer core

underneath the surface of the region, altering the electrical current of the region and thus the magnetic field strength of the region (Johnson-Groh and Merzdorf, 2020). It is also believed that the increase in pace of the raised strength of the anomaly is indicative of an imminent – or already occurring – magnetic pole shift.



This region can be incredible hazardous for low-Earth orbit satellites in the Earth's atmosphere; when a satellite is hit by a high-energy proton while travelling through the region, it can greatly hinder and cause malfunctions in equipment on-board. This occurs approximately once a month, with a few hours of data lost on average, but is rarely more impactful. On Earth, the South Atlantic Anomaly has recently been shown to have an impact on ship compasses, causing them to travel around in circles (Martin, 2020). The GPS identification systems (AIS) have been known to mistakenly display ships moving around in circles as a result of interference, but this was the first time that it had been documented to actually be happening. Since the ship was using a magnetic gyrocompass off the coast of Africa, the South Atlantic Anomaly had changed its direction, forcing it and 4 other nearby ships to move away from their planned routes. Since the affected region has increased in the last five years, this problem is also attributed to the incoming shift in the Earth's magnetic poles.

The Magnetic Pole Shift

A switch in the magnetic polarity of the Earth's magnetosphere is not a new concept: scientists have discovered that these shifts occurred multiple times in the planet's history, approximately every 300,000 - 400,000 years. However, according to the evidence of magnetic readings that they have, the last flip occurred around 780,000 years ago – indicating that a reversal is long overdue (Kim and Orwig, 2021). In 1831, the North Magnetic Pole was measured to be located in the Nunavut region of Northern Canada by explorer and scientist James Clark Ross. It was documented to have been continuing to move, and in the mid-1990s its speed had increased, from 15km to 55km per year (Witze, 2019). In 2018, the pole crossed the International Date Line, and is now headed towards Siberia (northern Russia).

The whole reversal process takes thousands of years to finish, but its impacts can still be felt while it is occurring. A variety of animals, including birds and salmon, use the magnetic fields of the Earth to instinctively calculate migration routes; as a result of a pole flip, these animals' migration will be greatly altered (Drake, 2018). A pole reversal will, for some time, create multiple regions which appear as 'poles' - which could cause modern magnetic-based technology such as GPS systems to malfunction, depending on how our society exists at that time. The shift in poles will weaken the strength of the Earth's magnetic field lines in some places – which could leave us more exposed to the dangerous solar radiation from which we are currently protected from. This could potentially cause malfunctions in aircraft, making flight less safe. At an extreme level, the shift could result in some areas of the Earth being rendered inhabitable.

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