St Benedict's
Journal of Science

including the *History & Philosophy of Science* and

6th FORM CHAPTER

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Ora et Labora

St Benedict's
Catholic School

The Catholic Secondary School for West Suffolk

Editor-in-Chief: Mr J Gregory
Associate Editors: Mr J D'Mello, Miss S Cleaver, Ms E Coogan and Mr J Senior

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Welcome to Volume 5 Number 1

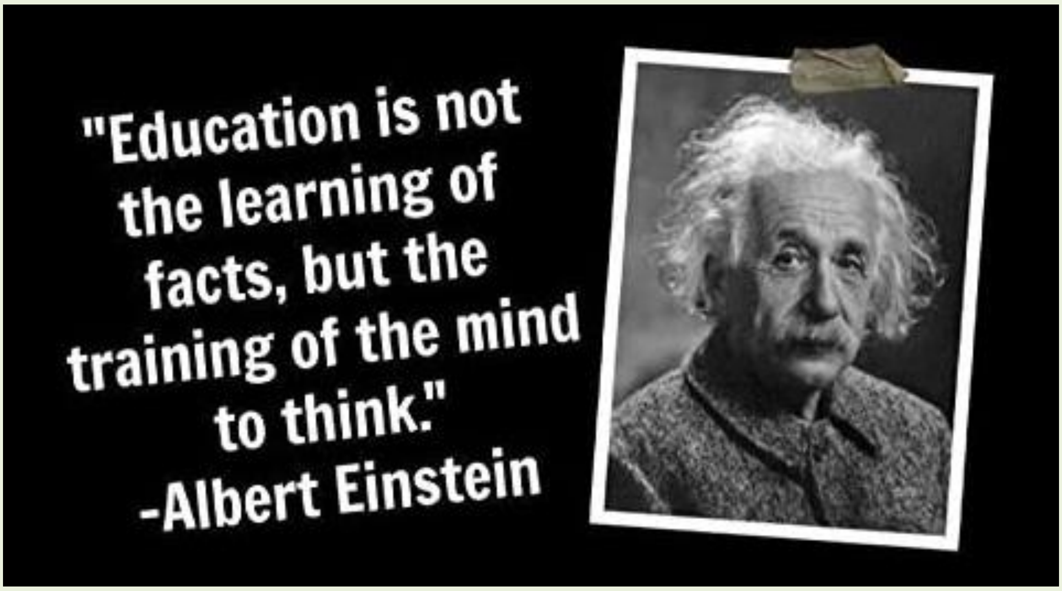
Just when we thought that, after getting back to school in September 2020, we could look forward to a full, ‘normal’ academic year – we are now back in lockdown.

This edition of the *Journal* covers the autumn term and features prominently the work of the Year 7s. It is always pleasing to receive work from this year group as they are embarking on their *Secondary Education* phase which will be so important for their *Further/Higher Education*, their career prospects and, ultimately, the rest of their lives.

There were also three papers submitted by Year 9 and Year 11 students, as well as another splendid contribution from three of our 6th Formers (Year 13).

Occasionally a paper is submitted that is considered to be of significant importance, not just in the narrow confines of a scientific discipline. We are therefore pleased to open this edition with a *SPECIAL EDITORIAL PAPER: School Council Focus on the Environment* by the Year 11 council member, Fionnghuala Leighton-Scott.

When it comes to education, at whatever age, perhaps Albert Einstein sums it up perfectly:



The Science Department also publishes two monthly newsletters:
SCIENCE NEWS *Monthly* and, for the astronomers, **NIGHT SKY NEWS**.

These are posted on the school’s Facebook and Twitter accounts.

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SPECIAL EDITORIAL PAPER

The following paper has been especially chosen to open this 5th volume of the Journal of Science:

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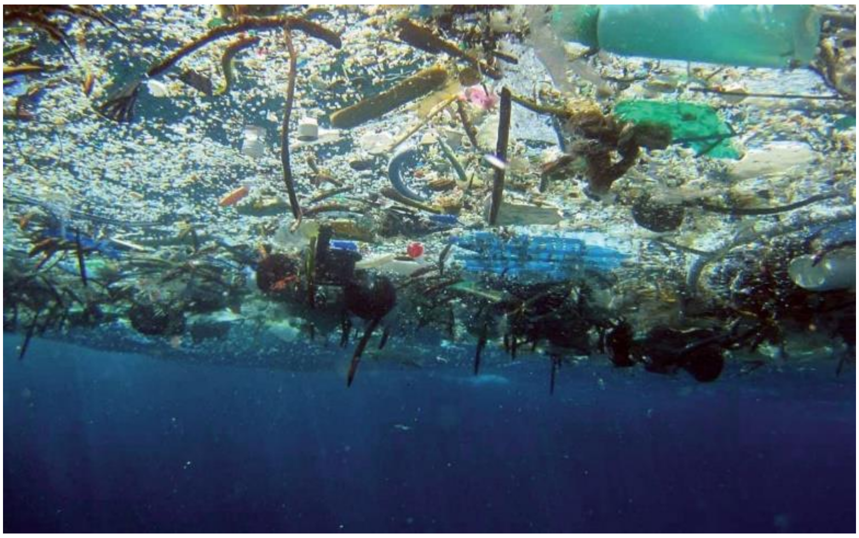
SPECIAL EDITORIAL PAPER

SCHOOL COUNCIL FOCUS ON THE ENVIRONMENT

Fionnghuala Leighton-Scott (Year 11)



This is what we as destructive humans have driven: a species oblivious to the danger and damage we have inflicted on our incredible, intriguing world.

Our lunches are wrapped in tin foil, and cling film, and plastic bags. Our waste is dumped in landfills, on the field and in the ocean. Our use of plastic is contributing to the loss of 150 species each day, decreasing the 10 years we have to prevent permanent damage due to climate change and causing over 100 million marine animals to die each year from plastic alone.

How can our lunch waste be prevented?

We live in a fairly affluent area where, when we can, we are able to prevent the promotion of plastic production through petitions and taking part in elections such as deciding who our mayor, MP and Prime Minister are. Some people think that their individual actions to combat climate change are a hindrance and a colossal waste of their time and money. But if every one of us had that mind-set then if we all threw away one bag of crisps each then that would be 7.8 billion pieces of rubbish. If every one of us has that mind-set, then who decides who runs our parliament? If every one of us had that mind set, then who signs petitions to create a more just world? Not everything that is faced can be changed, but nothing can be changed until it is faced.

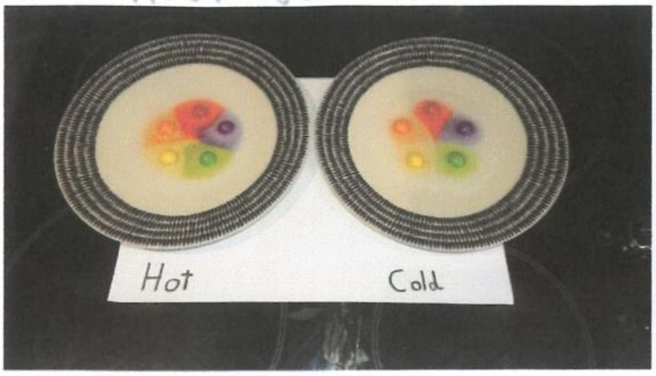
Sea levels are rising rapidly, currently increasing by 3 inches every ten years. The rising water level is mostly due to a combination of meltwater from glaciers and ice sheets and thermal expansion of seawater as it warms. This is partly because of the manufacturing of the plastic packaging that we use when preparing our packed lunches. In everyday life you can reduce the amount of plastic that you use by buying a stainless steel water bottle and lunch box or potato skin packaging to put your sandwich in. You can also buy locally produced essentials such as meats, vegetables and fruit from the Bury St Edmund's market stalls every Wednesday and Saturday 8.30am to 4pm despite the lockdown that we are currently under.

Most people think that climate change is something that is lingering and loitering far off in the future. But it is not. At this rate climate change is irreversible in less than ten years. To echo the words of Sir David Attenborough "The future of humanity and indeed, all life on Earth, now depends on us."

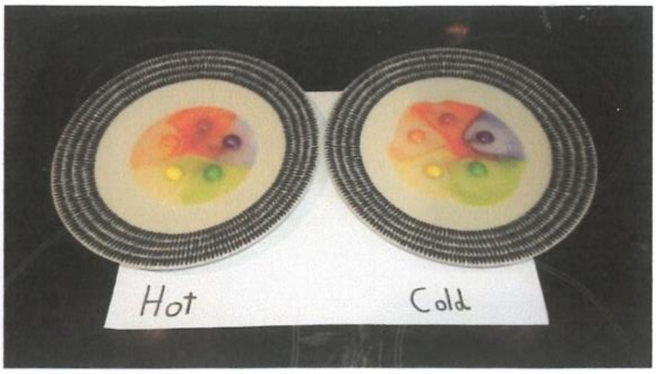
EDITOR'S NOTE: The following pieces of work are from Year 7 students who were tasked with investigating the effect of temperature on the rate of diffusion. They were set this task as 'homework', using skittles (the coloured sweets) and tea bags. This shows that you do not necessarily need a laboratory to safely carry out a scientific experiment – you can use your own kitchen!

ISABEL BASHAM 7C

SKITTLES EXPERIMENT



1 MINUTE



5 MINUTES

I put five skittles on each plate and added 15cm^3 of hot water to one plate and 15cm^3 of cold water to the other plate. I then timed the diffusion for 1 minute and 5 minutes.

The amount of diffusion was about the same, but the skittles in hot water did dissolve a bit.

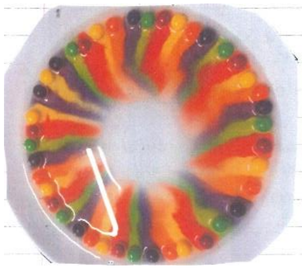
TEA BAGS EXPERIMENT

I put 200cm^3 of hot water in a short mug and 200cm^3 of cold water in a tall mug. I then put a tea bag in each mug and timed the diffusion over 10 minutes.

The amount of diffusion was greater in the hot water than in the cold water.

TANIA ROY 7C

SKITTLES AND TEA BAGS EXPERIMENT

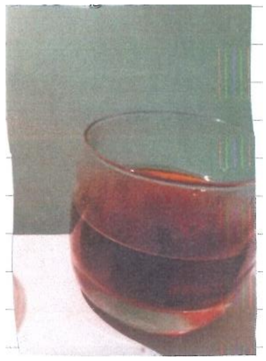


Skittles in water: this picture shows that the skittles' colours are diffusing towards the centre of the plate. This happened much faster when I used hot water.

The skittles showed diffusion in the hot water more than in the cold water because the colours were quicker to reach the middle of the plate. In the cold water the colours did get to the middle of plate, but very slowly.

It happens faster with the hot water because it has more energy and the skittles themselves get hotter.

Tea bag in cold water: the water changed colour when I mixed it; however, when I did not it stayed the same colour and did not get any darker. This shows that there is some diffusion in the cold water, but not so much.



Tea bag in hot water: the hot water became very dark without even mixing it. This shows that the hot water makes diffusion happen much quicker.

WHO INVENTED THE TEA BAG?

We certainly take them for granted and there is actually no one alive today who can recall a time without them – so who invented them? For the answer to this question we must go back to 1908.

Tea arrived in the UK in the 17th century and consisted of small fragments, the 'tea leaves', that had to be left in very hot water for a while but then removed for the liquid tea to be drunk. Although attempts were made to hold the 'leaves' in some sort of perforated container, they were not successful and everyone used a simple strainer.

Needless to say, it was in America, with its love of labour-saving devices, that tea bags were first developed. In around 1908, **Thomas Sullivan**, a New York tea merchant, started to send samples of tea to his customers in small silken bags. Some assumed that these were supposed to be used in the same way as the metal infusers, by putting the entire bag into the pot, rather than emptying out the contents. IT WAS THUS BY ACCIDENT THAT THE TEA BAG WAS BORN!

RYAN JOHN 7C

KITCHEN PRACTICAL: TEA BAGS EXPERIMENT

When I inserted a tea bag into a glass of cold water, I could see lines appearing like marks. The water changed colour slightly: it went from transparent to yellow/orange. I waited a few minutes and I could see it change to a strong orange colour. It took ages to change colour. My brother dared me to drink it, so I did. It tasted like water with a slight taste of tea and was bitter.

*(**Editor's note:** eating and drinking in the laboratory is strictly forbidden at all times! However, under the circumstances of this 'kitchen practical' and given that no hazardous chemicals were involved, the author was within his rights to do a 'taste test'.)*

I did not have any skittles at home so I watched a video on YouTube about skittles in hot and cold water:

With skittles around the edge of a plate of water, in a flash you start to see the colour running towards the centre. This is caused by the molecular structure of the dyes used on the skittles making it easy to dissolve and then diffuse through the water. If you do this in cold water, it will happen more slowly than with hot water. This is because in the cold water the particles move much slower. In hot water the particles move more rapidly.

Here is a more scientific explanation: the food colouring molecules are bouncing around at random among a bunch of other water (H_2O) molecules. Another reason why the colours move towards the centre of the plate is gravity: the sugar that has dissolved is a lot more dense than water, so gravity pulls it towards the centre of the plate, which is a little bit lower. As diffusion continues, the different colours from the skittles are going to get more and more mixed. Another thing that will speed up this process is convection, which will mix the colours up.

There is an equation that describes diffusive motion - it is **Fick's Law of Diffusion**:

$$J = -D\frac{d\varphi}{dx}$$

With this equation we are able to calculate the speed at which molecules propagate through other molecules. It depends on the molecule that is propagating and what it is propagating through, of course. It also depends on temperature. If you were to use really cold water as opposed to hot water, the diffusion would be slower because the molecules are not moving around very fast and there is not a lot of motion, so they take longer to spread out. If you use hot water, there is a lot more motion and so the molecules spread out faster.

WHO INVENTED SKITTLES?

Although *Skittles* are produced by a division of the American confectionary giant, Mars, they were actually first produced in the UK back in 1974. It wasn't until 1979 that Mars took them over in the US. Although it is not clear exactly who invented them, one theory is that the person was a Mr Skittles!

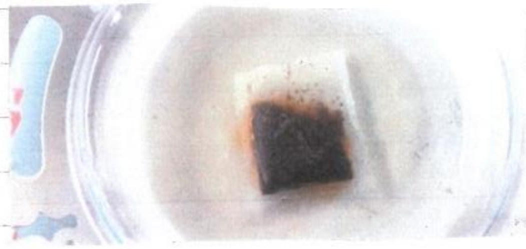
CLAUDIA SCOTT 7C

THE TEA BAGS EXPERIMENT

I used 2 tea bags and put one in a bowl of cold water and the other in a bowl of boiling water. Here is what happened:

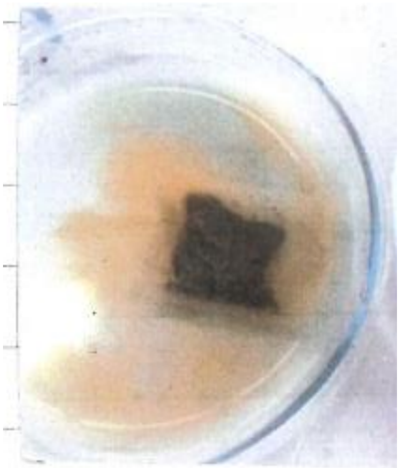
COLD WATER | **HOT WATER**

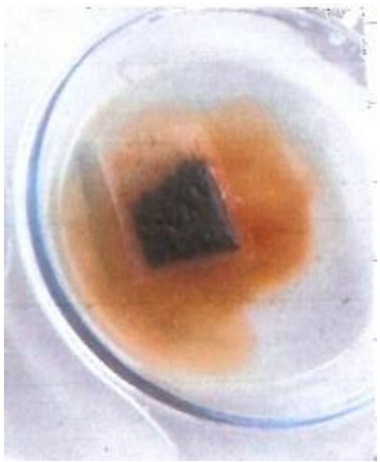
Stage 1:



Stage 2:

Stage 3:

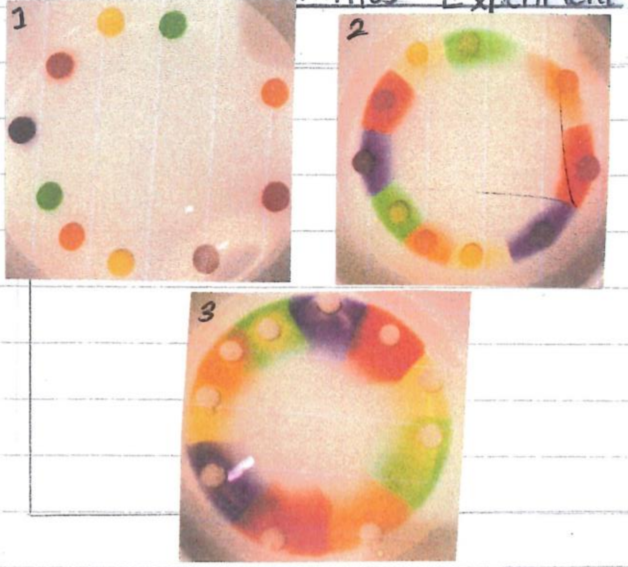




ELISHA GAMBOA 7C

SKITTLES EXPERIMENT

Skittles Experiment

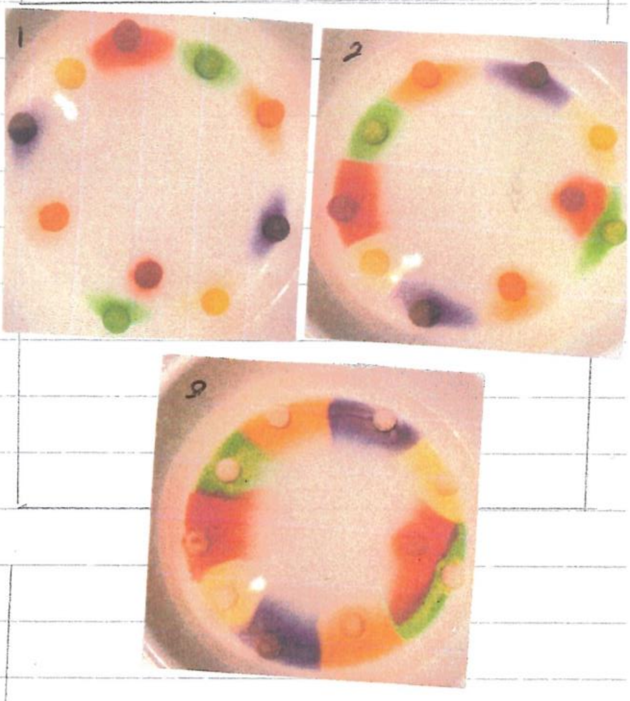


Cold Water

While conducting our experiment using cold water, we found it took 3 minutes and 13seconds for all the colouring to fade from all the skittles; this shows that the diffusion takes longer in cold water.

Hot Water

When we conducting our experiment with the hot water, it had taken 1 minute and 22sec for all of the food dye to fade off. This shows that the diffusion was quicker, because in hot temperatures it seems to have sped up.



Conclusion

This concludes that hot temperatures (in our case hot water) speeds up the process of diffusion.

Interesting we food during my experiment

While we where conducting our experiment, I observed that the darker colours absorb even more heat so even when you place it in cold (where the reaction is slower) the darker colours are still the quickest to react.

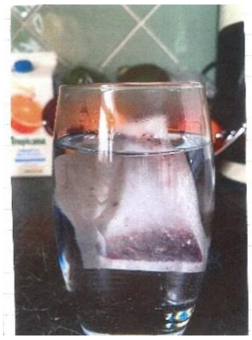
KAYTRINA BABBOO 7C

TEA BAG EXPERIMENT – IN PICTURES

Hypothesis: I think that the tea bag in hot water will diffuse quicker than in cold water.

HOT WATER

ONCE PUT IN



2 seconds later

15 seconds later

45 seconds later (end result)

COLD WATER

20 seconds

50 seconds

1 min 20 seconds

2 min 10 seconds

Conclusion: It is a fact that tea will diffuse quicker in hot water. This is because in hot water the molecules vibrate and have more energy; hence the tea will diffuse quicker.

IMAGINE THAT YOU ARE ON TOP OF MOUNT EVEREST AND FANCY A CUP OF TEA!

They have always found that it is difficult to make a decent cup of tea up Mount Everest. This is because, up there, water boils at 72°C rather than 100°C. And this isn't hot enough to make tea (that tastes nice!). So why is the boiling point lower?

The boiling point is lower because the air pressure is less at the top of the mountain. And boiling point depends on air pressure. In fact, the lower the pressure, the lower the boiling point. It's even possible to boil water at room temperature by reducing the pressure to nearly a vacuum!

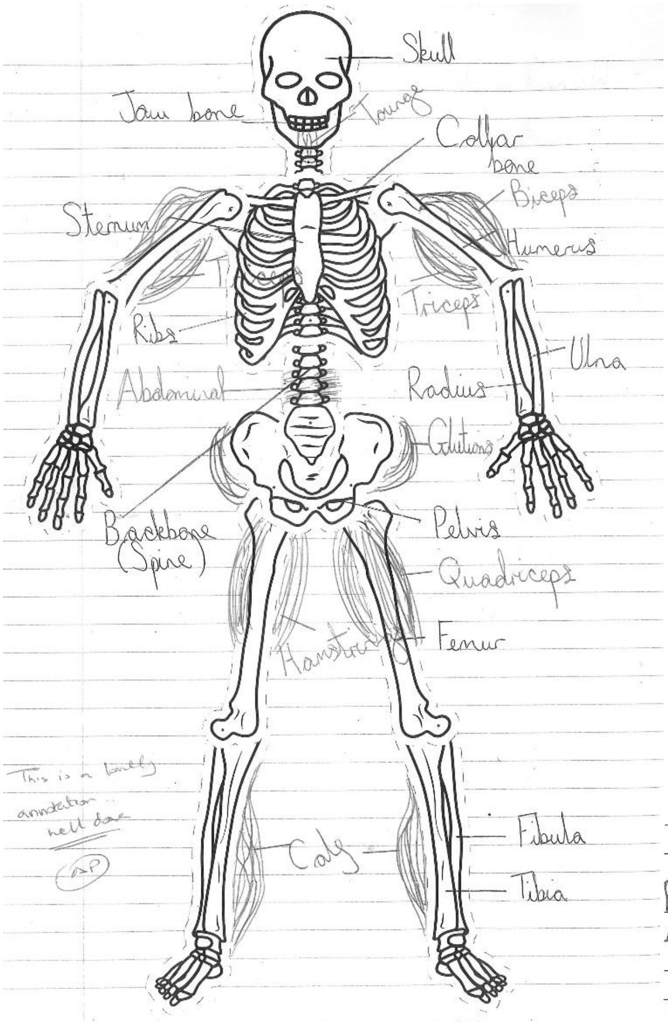
TOBY FLOOD 7C

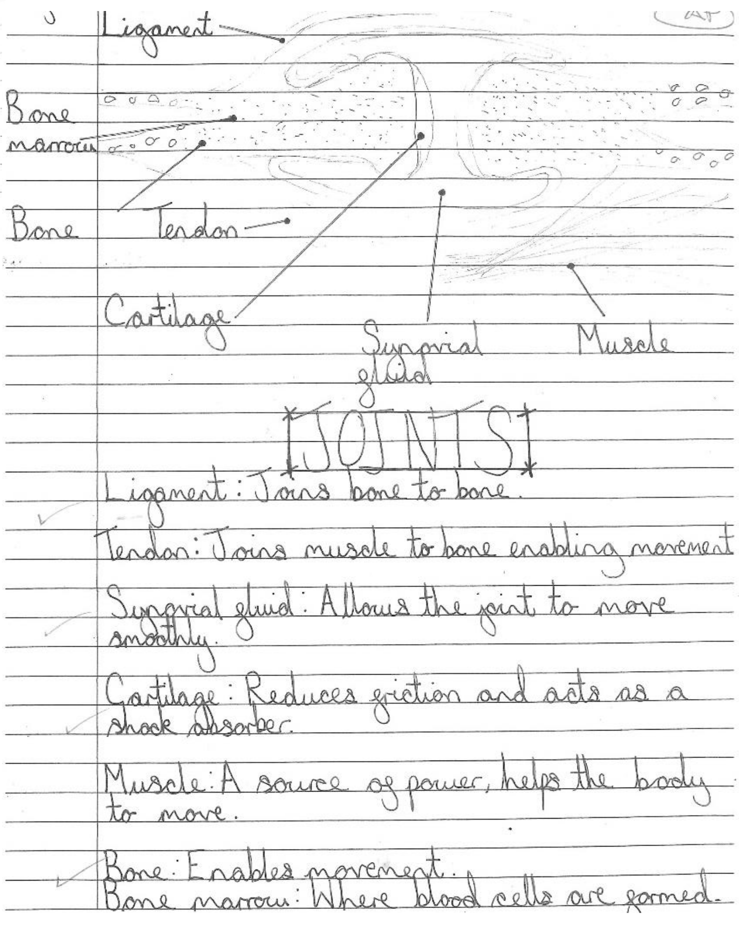
SKITTLES EXPERIMENT

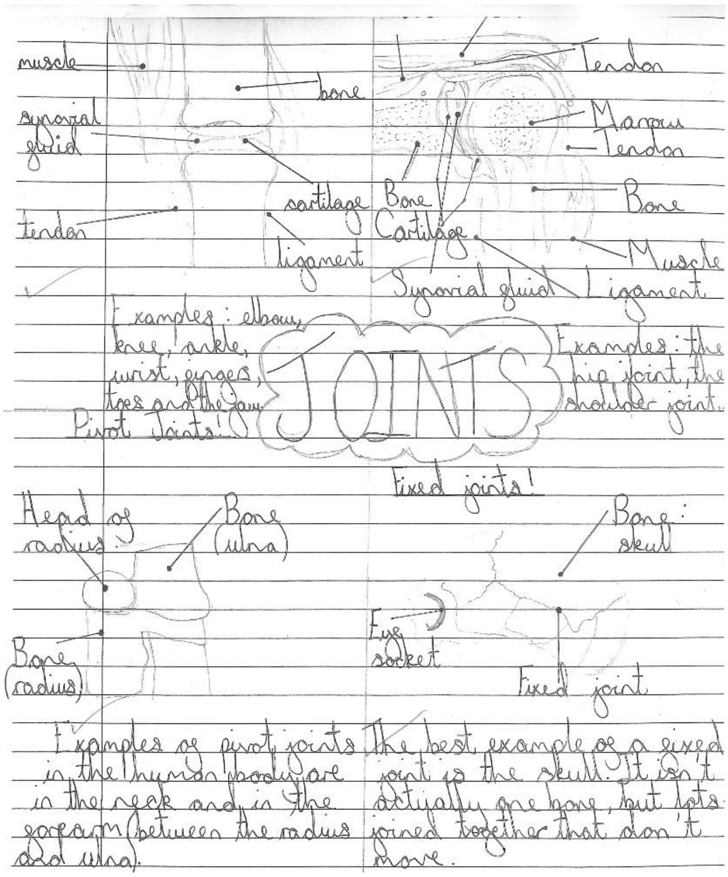
EDITOR'S NOTE: The following three papers/posters are such outstanding pieces of hand-written and hand-drawn work that it was decided to reproduce them in their original form. The editor apologises for any loss of clarity– this is entirely due to the scanning process and should in no way be seen as a reflection of the author's original work.

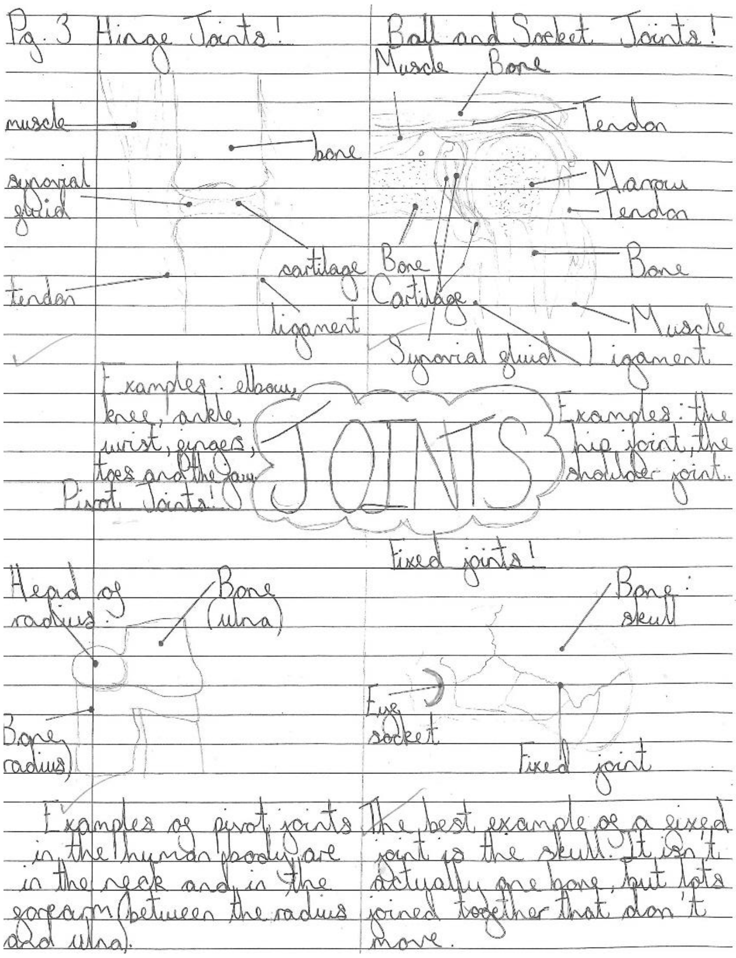
PHOEBE MORAN 7A

THE HUMAN SKELETON AND ITS JOINTS






muscle
bone
synovial fluid
cartilage
tendon
ligament
Tendon
Marrow
Tendon
Bone
Bone
Cartilage
Muscle
Synovial fluid
Ligament
Examples: elbow, knee, ankle, wrist, fingers, toes and the jaw
JOINTS
Examples: the hip joint, the shoulder joint.
Pivot Joints!
Fixed joints!
Head of radius
Bone (ulna)
Bone: skull
Eye socket
Bone (radius)
Fixed joint
Examples of pivot joints in the human body are in the neck and in the forearm (between the radius and ulna).
The best example of a fixed joint is the skull. It isn't actually one bone, but lots joined together that don't move.


Pg. 3 Hinge Joints!
Ball and Socket Joints!
Muscle
Bone
muscle
bone
synovial fluid
cartilage
tendon
ligament
Tendon
Marrow
Tendon
Bone
Bone
Cartilage
Muscle
Synovial fluid
Ligament
Examples: elbow, knee, ankle, wrist, fingers, toes and the jaw
JOINTS
Examples: the hip joint, the shoulder joint.
Pivot Joints!
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Head of radius
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St Benedict's NIGHT SKY NEWS 9 – Jan 2021

STARS IN YOUR EYES!

Although the Winter Solstice has passed and the nights are getting shorter, we are still in the depths of Winter.

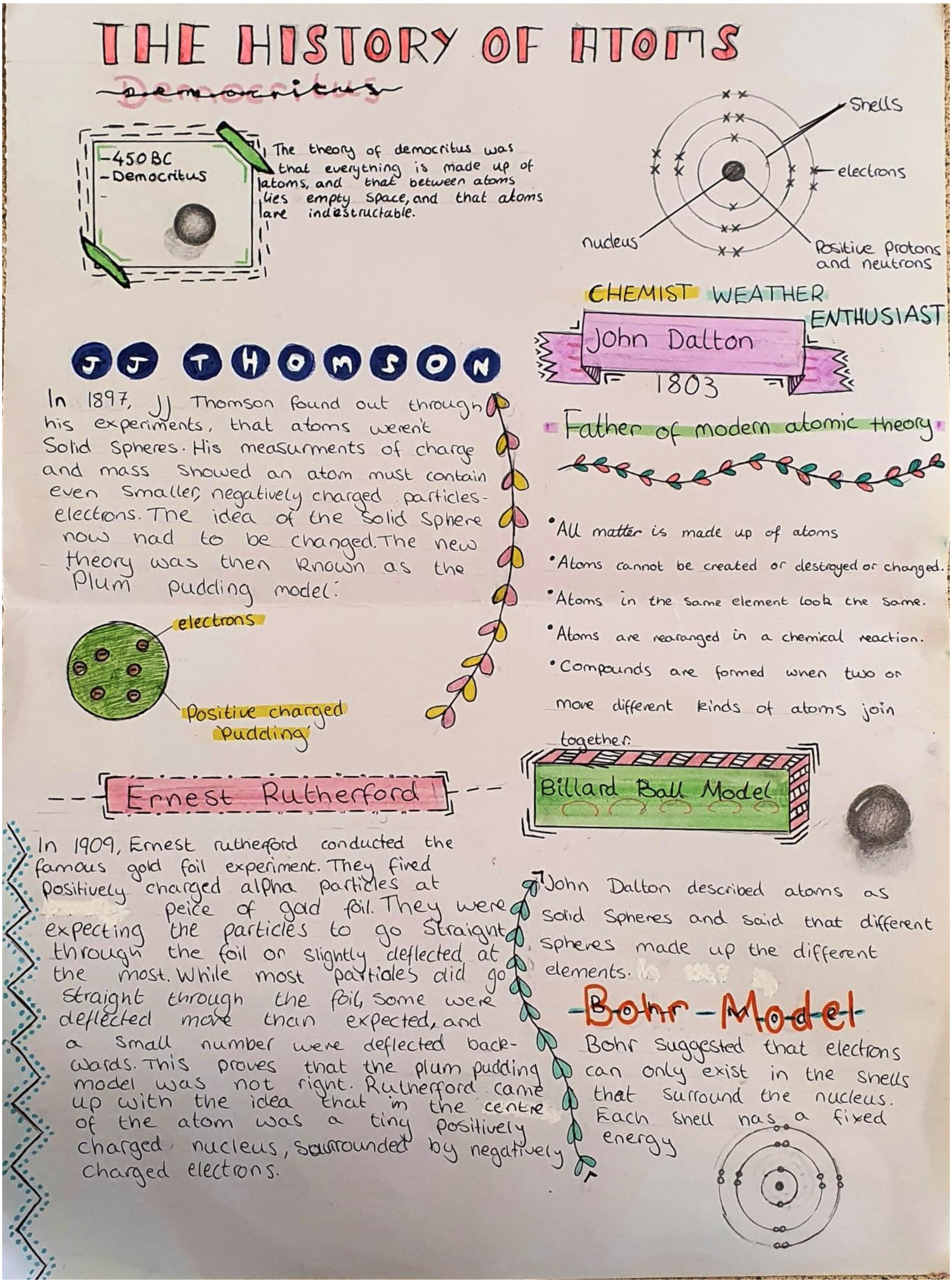
Between now and March the southern sky will be dominated by some of the brightest and most distinct constellations visible from the UK: the likes of Gemini (with its 'twin' stars Castor and Pollux); Taurus (with its 'eye of the bull' star, the orange giant Aldebaran; and the mighty 'hunter', Orion.

ORION is probably the most recognisable of all the constellations. From its 3 bright 'belt' stars one can find to the top left BETELGEUSE, the red supergiant. To the bottom right will be the bright, blue giant, RIGEL. Below the belt are the 3 rather dimmer stars of Orion's 'sword'. Note that the middle 'star' is not actually a star at all, but Orion's Great Nebula. Once you have familiarised yourself with this pattern of stars, it becomes easy to imagine the picture of a great hunter, with sword and shield!

Betelgeuse was in the news around this time last year because it appeared to dim considerably. This was temporary and it has now regained much of its usual brightness, although it is still variable.

PHOEBE TEVERSON 9X

POSTER – THE HISTORY OF ATOMIC THEORY



SPECIAL FEATURE

It is interesting to note, with some disappointment I might add, that the 'History of Atomic Theory' in KS4 omits arguably one of the greatest achievements of all: the discovery of the NEUTRON. Ernest Rutherford, himself lauded as the discoverer of the atomic nucleus and the proton, stated that the discovery of the neutron was of great importance in the understanding of atomic processes.

So who was it that discovered the neutron, the final piece in the atomic jigsaw puzzle?

JAMES CHADWICK

James Chadwick was born in Cheshire, England, on 20th October, 1891, the son of John Joseph Chadwick and Anne Mary Knowles. He attended Manchester High School prior to entering Manchester University in 1908; he graduated from the Honours School of Physics in 1911 and spent the next two years under Professor (later Lord) Rutherford in the Physical Laboratory in Manchester, where he worked on various radioactivity problems, gaining his M.Sc. degree in 1913. That same year he was awarded the 1851 Exhibition Scholarship and proceeded to Berlin to work in the Physikalisch Technische Reichsanstalt at Charlottenburg under Professor H. Geiger.

During World War I, he was interned in the Zivilgefangenenlager, Ruhleben. After the war, in 1919, he returned to England to accept the Wollaston Studentship at Gonville and Caius College, Cambridge, and to resume work under Rutherford, who in the meantime had moved to the Cavendish Laboratory, Cambridge. Rutherford had succeeded that year in disintegrating atoms by bombarding nitrogen with alpha particles, with the emission of a proton. This was the first artificial nuclear transformation. In Cambridge, Chadwick joined Rutherford in accomplishing the transmutation of other light elements by bombardment with alpha particles, and in making studies of the properties and structure of atomic nuclei.

In 1932, Chadwick made a fundamental discovery in the domain of nuclear science: he proved the existence of neutrons – elementary particles devoid of any electrical charge. In contrast with the helium nuclei (alpha rays) which are charged, and therefore repelled by the considerable electrical forces present in the nuclei of heavy atoms, this new tool in atomic disintegration need not overcome any electric barrier and is capable of penetrating and splitting the nuclei of even the heaviest elements. Chadwick in this way prepared the way towards the fission of uranium 235 and towards the creation of the atomic bomb. For this epoch-making discovery he was awarded the Hughes Medal of the Royal Society in 1932, and subsequently the Nobel Prize for Physics in 1935.

Chadwick was a member of the British MAUD Committee, which concluded that the creation of nuclear weapons was possible and even inevitable. This supposition contributed towards President Roosevelt's decision to build the atomic bomb. Additionally, Chadwick was an integral figure in the Tube Alloy Project—the codename for the British program to devise and develop nuclear weapons. His overtures to government officials in the UK and US were central to UK-US cooperation.

From 1943 to 1946, Chadwick headed the British Mission to the Manhattan Project. He also served as the technical advisor to the US-Canadian-UK Combined Policy Committee, which coordinated control of the project between the three nations involved. In 1944, Chadwick moved his family to the Project's main research facility in Los Alamos. Finding the housing conditions distasteful, his twin daughters objected to the move, and so the family relocated to Washington D.C. where he continued to contribute to the Project's efforts. He observed the first atomic explosion, known as the Trinity test.

https://www.nobelprize.org/prizes/physics/1935/chadwick/biographical/

https://www.atomicheritage.org/profile/james-chadwick

LINDA BABY 11P

INTERGALACTIC SUPER-LIGHT SPEED SPACE TRAVEL: A FANTASY OR THE TRANSPORT OF TOMORROW?

Intergalactic space travel, a dream of every 5-year-old kid or the transport of tomorrow? Intergalactic super-light speed space travel is the hypothetical travel between galaxies. How this is possible some may ask but, it's all down to these scientific phenomena: black holes, white holes and finally worm holes that are sure to make this dream come true.

So what are black holes, white holes and worm holes?

NASA describes a black hole as "a place in space where gravity pulls so much that even light cannot get out". As no light can get out, people can't actually see black holes, they are invisible however; it doesn't mean that they don't exist, thanks to technology, space telescopes with special tools can help find black holes. Scientists can see how the strong gravity affects the stars and gas around the black hole so, the big question is can one destroy the Earth? No, black holes don't go around space eating stars, moons and planets which is a common misconception of these amazing creations. However, if you find yourself in one, you won't be heard from again. Ever since Albert Einstein's general theory of relativity was considered to have predicted black holes by linking space-time with the action of gravity it has been said that black holes are formed from a death of a star. Black holes are spheres of no return and white holes on the other hand are spheres of no admission. General relativity describes white holes in theory so; no one actually knows how one might form. "How does a black hole die? We don't know. How is a white hole born? Maybe a white hole is the death of a black hole." (Rovelli)

So where do wormholes come into this? "A wormhole is a tunnel-like connection through space-time much like the real tunnels bored by worms in a (Newtonian) apple." Yes, that apple which inspired Newton to make one of the biggest scientific discoveries of all time. Wormholes are theoretically "tunnels" between two points of space caused by twisting (warping) of space time. Albert Einstein's theory of general relativity describes how space-time warps around massive objects such as black holes but, is it too far-fetched? Wormholes contain two mouths with a throat connecting the two, Einstein's general theory of relativity mathematically predicts the existence of wormholes but, none have been discovered, YET.

What's the use of intergalactic space travel and is it possible?

In 1935, Einstein and physicist Nathan Rosen used the theory of general relativity to explain the idea of the existence of some sort of "bridges" through space time. These bridges connect two different points in space-time, theoretically cutting a shortcut that could reduce travel time and distance; these shortcuts are now known as Einstein-Rosen bridges or more commonly wormholes. What's the big deal about wormholes? The answer is that wormholes might provide a shortcut to other parts of the universe providing an easy route to understanding some of the deepest questions about the nature of our universe. But, as good as it sounds Einstein did also predict that if one did exist, it would be unstable and we wouldn't be able to use it for practically travelling through time. (I know it was disappointing for me too). All theories are only at a hypothesis stage and most likely not to be tested.

The first use of the term *"wormhole"* is attributed to the American physicist, JOHN ARCHIBALD WHEELER, in a 1957 paper co-authored by Charles Misner.

This analysis forces one to consider situations ... where there is a net flux of lines of force, through what topologists would call "a handle" of the multiply-connected space, and what physicists might perhaps be excused for [for] more vividly terming a "wormhole".

—Charles Misner and John Wheeler in *Annals of Physics*

ADRIAN SMITH-DELGADO 11S

MEASURING SPEED IN AERONAUTICS

As altitude increases, the density of air decreases: and since airflow [air pressure & density] is vital when it comes to navigation and manoeuvres, a conventional ground speed indicator (also known as a TAS [True Airspeed Indicator] indicator) is irrelevant at higher altitude. This is where the need for an Indicated Air Speed [IAS] arises, an IAS is typically measured using a pitot tube....

Pitot Tubes

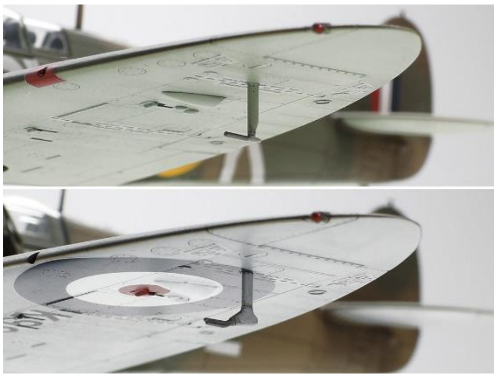


Figure 1 - The Pitot tubes of a [Model] Spitfire Mk Ia

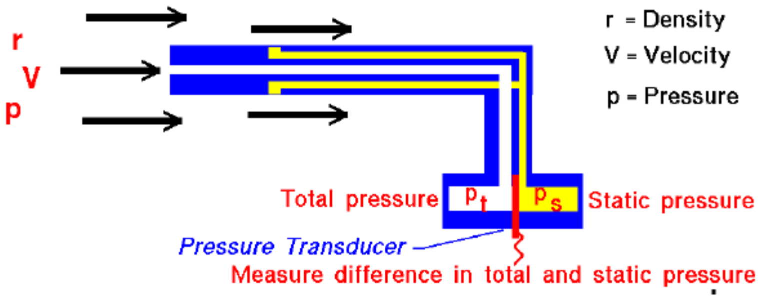


Diagram 1 – A diagram of a pitot tube

Pitot tubes have a centre hole, as well as numerous small holes which are drilled on the outside of the tube: these small holes drilled on the outside channel air through tubes [shown in yellow on the diagram] to one side a pressure transducer, a device which monitors the pressure a fluid/medium inflicts upon it. The centre hole also has a tube, however it does not connect to the smaller tubest, rather it connects to the other side of the transducer. The transducer measures the difference in pressure on both sides of it, by the use of an electronic strain gauge which uses pressure to create an electrical resistance which can then be measured.

The pitot tube as a whole is mounted in a such a way that the centre tube is constantly facing in the direction of travel, with the smaller holes perpendicular to it: on older properllor driven aircraft pitot tubes were mounted on the wings due to the prop air flow, however in jet turbine driven aircraft the pitot tube is often mounter directly on the nose so as to be the furthest forward part of the aircraft.

How does it work ?

A pitot tube utilises Bernoulli's equation:

- The smaller outer holes are perpendicular to the centre hole/tube, this means they are exactly perpendicular to the direction the aircraft is travelling.
- The random and ordered components of the air velocity pressurise the central tubes, while the smaller holes' tubes are pressurised only by the random component
- The pressure in the smaller holes' tubes is referred to as the static pressure in Bernoulli's equation

- The pressure in the centre hole's tube is referred to as the total pressure in Bernoulli's equation
- The pressure transducer simply monitors the difference between the total pressure and static pressure by subtracting one from another.
- Pressure Transducer reading = **pt – ps**

Bernoulli's Equation and finding a Velocity

Bernoulli's Equation:

$$\left(P_s + \frac{rv^2}{2}\right) = P_t$$

Assuming the pressure differences and air density are known, Bernoulli's equation can be utilised to find the aircraft's velocity. Bernoulli's equation states:

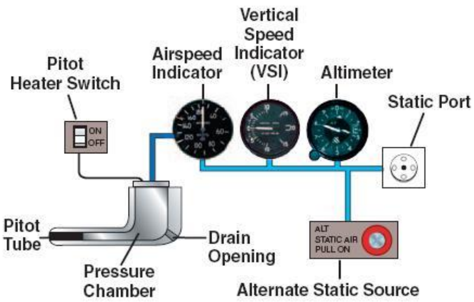
"The total pressure is equal to the sum of static pressure and half the fluid/medium density multiplied by the velocity squared"

Thus, Bernoulli's equation can be rearranged to find velocity:

$$v^2 = \frac{2(P_t - P_s)}{r}$$

The PITOT tube is a classic fluid dynamic sensor named for its inventor, Henri Pitot, who in the 18th century developed it to measure the speed of rivers and canals in France.

HENRI PITOT (May 3, 1695 – December 27, 1771) was a French hydraulic engineer and the inventor of the pitot tube. He rose to fame with the design of the Aqueduc de Saint-Clément near Montpellier (the construction lasted thirteen years), and the extension of Pont du Gard in Nîmes. In 1724, he became a member of the French Academy of Sciences, and in 1740 a fellow of the Royal Society.



In aeronautics, pitot tubes have been used for many years and, in conjunction with other pressure-sensitive devices, form what is known as the *pitot-static system*. The system is designed to determine an aircraft's airspeed, Mach number, altitude, and altitude trend.

The sad fact is that the system is not infallible, with tragic consequences. There are several situations that can affect the accuracy of the pitot-static instruments. Some of these involve failures of the pitot-static system itself—which may be classified as "system malfunctions"—while others are the result of faulty instrument placement or other environmental factors—which may be classified as "inherent errors".

One such "environmental factor" was implicated in the disappearance of an Air France Airbus A330 passenger jet (flight AF447), on June 1 2009. It was a scheduled international passenger flight from Rio de Janeiro, Brazil, to Paris, France. On 1 June 2009, the Airbus A330 serving the flight stalled and did not recover, eventually crashing into the Atlantic Ocean at 02:14 UTC, killing all 228 passengers and crew.

France's Bureau of Enquiry and Analysis for Civil Aviation Safety (BEA) was hampered because the aircraft's flight recorders were not recovered from the ocean floor until May 2011, nearly two years later.

The BEA's final report, released at a news conference on 5 July 2012, concluded that the aircraft crashed after temporary inconsistencies between the airspeed measurements—likely due to the aircraft's pitot tubes being obstructed by ice crystals—caused the autopilot to disconnect, after which the crew reacted incorrectly and ultimately caused the aircraft to enter an aerodynamic stall, from which it did not recover. The accident is the deadliest in the history of Air France, as well as the deadliest aviation accident involving the Airbus A330

6TH FORM CHAPTER

ABIGAIL LAU 13A

INTERSPECIFIC COMPETITION: WHY IS IT MORE INTENSE THE MORE CLOSELY RELATED TWO SPECIES ARE?

Interspecific competition occurs when two or more different species of organism compete for the same resource. Competition occurs when resources are limited and there is not enough of a given resource available to be shared between species that both need it. The competitive interaction results in a reduction of the resource available to both populations. *A species is the smallest and most taxonomic group*. In interspecific competition it is discussing two or more different species. However, if they share the same Genus, for example red squirrels and grey squirrels are both from the Genus *Sciurus*, they are more closely related than species that do not share the same Genus such as Lions and Hyenas. The effects of closely related species will be discussed.

Interspecific competition will either happen because of interference or exploitation. Interference being more direct e.g. the two different species actively fighting i.e. "interfering" with each other and their access to the resources or exploitation which is a more indirect form of interspecific competition. Exploitation occurs when different species compete with each other but by exploiting the resource which results in less availability for their competitors.

An example of a resource competed for in interspecific competition is food. When different species compete for the same food source there will be less available for organisms of each species. This results in less energy transferred to each species for both growth and reproduction. The decline in reproduction effects population sizes. This highlights that when interspecific competition occurs there will be smaller population sizes for both species in comparison to if only one species had been present in the habitat.

An ecological niche is the role of an organism or population has in an ecosystem. Each species has a different set of adaptations and so they do not directly compete for the same resources as they have their own niche. When species have different niches they can co-exist in an ecosystem without limiting resources from each other which will reduce population sizes. For example, some species live in a small range of temperatures whilst others might exist in a certain range of elevations e.g. different levels of a rainforest. *Each species responds differently to the distribution of resources and competitors so they each occupy their own niche.*

Interspecific competition happens between plants in a rainforest. Another example of a resource competed interspecifically between organisms is sunlight for plants, they require it to make their food source through photosynthesis. Some plants exist at different elevations of the rainforest for example some grow as tall as the Emergent Layer whilst some exist under the canopy. An example of a niche is vertical positioning in the forest. Some plants invest lots of their energy into growing tall. They spread out their branches to absorb as much sunlight as possible for optimum photosynthesis to grow without competition but their leaves are really small as the majority of energy is used to grow upwards. Further down in layers such as the Under Storey the plants are average sized taking up all the energy they can in order to compete with other plants. However, plants and trees in a rainforest can coexist because their adaptations and niches suit their elevation. The plants that grow below the tall trees will compensate by having leaves with a larger surface area so the sunlight can reach the leaves past the smaller sized leaves in the Emergent layer.

They have these niches to prevent exploitation of limited resources in this case sunlight. Plants competing for sunlight is an example of interspecific competition through exploitation. They aren't actively trying to compete with each other but in dense forests tree species might not be adapted to prevent lack of sunlight reaching other plants below. This is because where there are mixed tree species, access to the resources may be easier for taller trees that are capable of absorbing more sunlight, making it less accessible to the shorter tree species shaded by them.

Interspecific competition can also occur between mobile organisms. Instead of physical adaptations to prevent extinction of a species. Gause's competition exclusion principle prevents imbalances in population sizes. According to the competitive exclusion principle, no two species which use the same resources in the same manner and same space can exist together; they must move apart from each other over time resulting in the one that uses the resources more effectively because it is better adapted to claim the majority or all of the sources before the other species will eventually eliminate the other.

Interspecific competition tends to be more intense the closer the two species are related. We can define species sharing the same Genus as being more closely related than those with derived from differing Genus. The reason why it tends to be the case is that members of the same species tend to have the same needs, whereas members of different species tend to have slightly different needs. The closer the two species are related the more similar their niches are. Since species can coexist if their niches are different since they don't compete a significant amount this is why closely related species have more intense interspecific competition. In some cases, species may undergo evolution through natural selection resulting in slight changes in their niches. This would further limit the effects of interspecific competition known as niche differentiation. Another outcome of interspecific competition is local extinction this will happen if one species does not evolve by adapting to coexist with its competitor.

Competition becomes more intense the more closely related two species are because their niches tend to be similar and according to Tilman's Model of competition if this is the case both species cannot coexist in the same habitat. Tilman's model uses consumption vectors which show the change in resource availability caused by consumption. The total amount of consumption depends on two variables: the consumption of an individual and the numbers of individuals. Consumption vectors are characteristics of species are able to be measured. *"In order for both species to coexist there needs to be a resource level in the environment at which the growth rate of birth species equal to zero."* In other words both species must be able to grow to have any chance of co-existence. This cannot be done if niches are the same.

The Lotka-Voltera model of competition describes the dynamics of biological systems in which two species interact, are as a predator and the other as prey. However, when species are both more closely related i.e. share the same Genus, they tend to be predators to the same resource.

INTERSPECIFIC COMPETITION is seen as a driving force in the overall evolutionary process; MACROEVOLUTION. There is also something called the *RED QUEEN HYPOTHESIS* which proposes that species must constantly adapt, evolve, and proliferate in order to survive while pitted against ever-evolving opposing species. It also gives us a clue as to why some species, for no apparent non-biological reason, die out.

An example observed of interspecific competition between two closely related species is the red squirrel *Sciurus Vulgaris* and the grey squirrel *Sciurus Carolinensus.* The population size of the grey squirrels increased rapidly when it started inhabiting areas of the UK and since the squirrels only reproduced in specific months (February and June) the red squirrels started to decline in population size. The reason the grey squirrels increased in population size and outcompeted the red squirrels for resources was due to the grey squirrel being better adapted for survival in the habitat as it was able to eat a wider range of food than the red squirrel. Red squirrels could only eat mature acorns while the grey squirrels were able to eat green acorns even if they had not fully ripened yet. This created food competition to the red squirrel. Both species fed on nuts, acorns, berries and barks. The grey squirrel not only took most of the food source from the red squirrel but could survive using alternatives such as the green acorn when the red squirrels were able to acquire its food source.

Furthermore, grey squirrels are larger in size so they can store more fat increasing their survival chances and ability to reproduce larger numbers. The red squirrel could not only outcompete the grey squirrel in acquiring enough food source but also could not reproduce enough to equalise and minimised the gap in the population sizes between the two species. An increase in the population size of grey squirrels reduces the food supply even more leaving less available for the red squirrels causing more deaths and endangering the species to possible extinction.

If we compare interspecific competition between two different species that aren't as closely related we can observe less intense competition for resources. For example, Hyenas which are derived from the Genus *Hyaena* and Lions from the Genus *Panthera* do not have as much of a detrimental effect on each other's population size even though they do compete for territory. Hyenas and lions inhabit the same areas and hunt the same prey. They steal food from each other and kill each other's young but Hyenas outnumber lions in population size so why aren't the lion species declining? Hyenas and Lions have different niches and these niches enable to them to coexist following Gause's competition exclusion principle. They use their prey in a different "manner". Hyenas are the most abundant predator in Africa and there are four different extant species of Hyena which have different feeding niches therefore their role in an ecosystem is to keep the balance between populations of prey and predator. On the other hand, Lions are an Apex predator, the top of the food chain and because of this are less likely to be effected by interspecific competition. Despite the Hyenas' large population size Lions are stronger and better adapted to compensate and survive against the competition. They are different species with different roles in an ecosystem. This ability to coexist provides evidence to why less closely related species have less intense competition. In addition, Hyenas and Lions might share the same habitat but their active territorial competition ensures they don't occupy the same area making their competition less intense to the extent of populations becoming extinct unlike the closely related squirrel species. Hyenas and Lions actively fight aggressively and even kill each other, squirrels do not in comparison. Interspecific competition will be more intense the more closely two related species are because they share niches that are too similar.

Looking at another example of two closely related species, Lions and Tigers, they share the same Genus *Panthera.* Tigers are also apex predators in an ecosystem but they don't coexist because they occupy different locations (Lions in Africa and Tigers in Indian and Bangladesh) and therefore are not in competition with each other. This follows Gause's competition exclusion principle "no two species which use the same resources in the same manner and same space can exist together; they must move apart from each other over time".

If we put Tigers and Lions within a closer proximity and location would we expect the same effect as the grey squirrels moving to the UK on the red squirrels? They share the same Genus, are both an apex predator so would have similar niches proving evidence for the reason why competition would be more intense. Lions tend to be more social so they are more likely to eliminate the Tiger population as Tigers are more solitary so when they hunt for resources the Tiger would be outnumbered and easily killed. From this, Lions seem better adapted to compete for resources in the same location so we would expect a more intense competition between them.

In summary, interspecific competition is more intense between species that are more closely related to each other. We define them being more closely related if they are derived from the same Genus and are more likely to have similar niches. Niches that are too similar cannot coexist as the competition is too intense and will result in extinction of the less adapted species for survival or they will evolve and result in niche differentiation. Competition both intraspecific and interspecific threaten species' population sizes and can lead to extinction but should humans/conservationists intervene? My conclusion to that is no on one condition. If the species weren't introduced to the habitat by humans, they are there for a reason. We should only intervene if the niches are too similar that is increasing the risk of making a species extinct. We need to protect animals but competition between species such as Hyenas and Lions occur because of nature. Interspecific competition is more intense the more closely related two species are but the bigger effects of this are usually seen when humans themselves introduces species to a foreign area where they shouldn't be. When species coexist their niches should balance out and if naturally the competition is too intense then naturally it occurs for evolution.

WHO ARE OUR COMPETITORS and WHERE IS EVOLUTION TAKING US?

By and large we humans coexist here on Earth with little competition from other species or, where there is competition, we tend to dominate. There are exceptions, of course, such as when we venture unprepared into the oceans or wildlands! So, if interspecific competition is a driver for the evolution of a species, are we ourselves evolving and, if so, what is driving us?

People commonly assume that our species has evolved very little since prehistoric times. Yet new studies using genetic information from populations around the globe suggest that the pace of human evolution increased with the advent of agriculture and cities. If we are still evolving, what might our species look like in a millennium should we survive whatever environmental and social surprises are in store for us? Speculation ranges from the hopeful to the dystopian!

Steve Jones of University College London has argued that human evolution has essentially ceased. At a Royal Society of Edinburgh debate in 2002 entitled "Is Evolution Over?" he said: *"Things have simply stopped getting better, or worse, for our species. If you want to know what Utopia is like, just look around—this is it."* Jones suggested that, at least in the developed world, almost everyone has the opportunity to reach reproductive age, and the poor and rich have an equal chance of having children. Inherited disease resistance—say, to HIV—may still confer a survival advantage, but culture, rather than genetic inheritance, is now the deciding factor in whether people live or die. In short, evolution may now be memetic—involving ideas—rather than genetic.

This is a rather stark hypothesis, but many consider that there is some truth in the assertion to evolution involving our ideas and inventions, especially our development of AI (Artificial Intelligence). Indeed, there is a proposed evolutionary route called the *BORG ROUTE* that predicts that human evolution will be one of symbiosis with machines – a human-machine synthesis. It is clear that we are already largely dependent on machines, so maybe we shall eventually link our bodies with robots, or even upload our minds into computers.

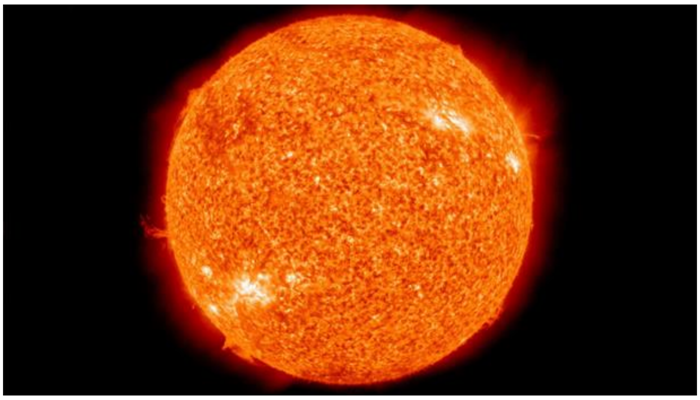
For a more complete treatment of this topic, please follow the link:

https://www.scientificamerican.com/article/what-may-become-of-homo-sapiens/

PIERRE HORNSBLOW 13P

NUCLEAR FUSION: THE FUTURE OF CLEAN ENERGY

Nuclear fusion reactors



Nuclear fusion is famously what powers our sun, individual fusion reactions can yield around four times as much energy as the standard fission of uranium 235 used in today's nuclear power plants and the only possible individual reaction which could yield more energy per kg would be matter-anti matter annihilation. This and the fact that the raw materials needed are deuterium (which can be found in sea water at a concentration of 33 mg/l) and lithium which is used to make tritium, a third radioactive Isotope of hydrogen, mean that extensive research has gone into the development of fusion nuclear powerplants, as it seen as a much cleaner and safer alternative to fossil fuel or fission reactions.

Key definitions:

Strong force- the strong force acts between all subatomic particles which have colour, and is modeled to be carried by gluons. With a range of around 1 X 10^{-15} m it is about 137 times as strong as the electromagnetic force, and the strength of the force doesn't decrease as the distance between two quarks is increased (up to the 1 X 10^{-15}m) such that the energy put into the separation of two quarks is strong enough for the production of extra quarks.

Nucleons: refers to protons or neutrons which are in turn made up of quarks meaning they are subjected to the strong force when close enough to each other, such as inside the nucleus.

Toroid: mathematical shape, such as a doughnut, used in tokamak reactors.

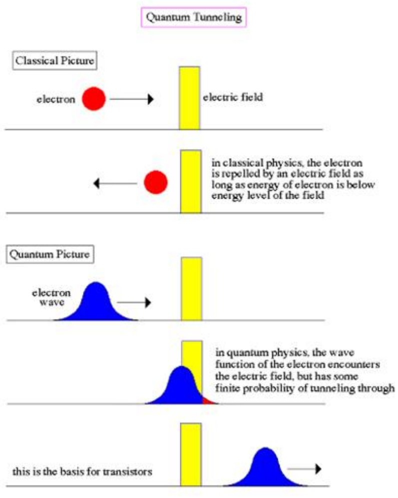
Coulomb barrier: the energy barrier due to the electrostatic repulsion of two nuclei which must be overcome for nuclear reactions to occur.

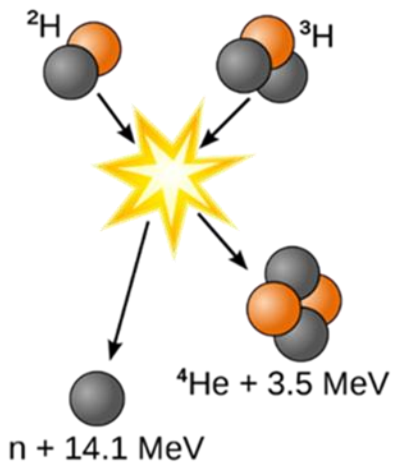
Plasma: the fourth fundamental state of matter, in the universe over 99% of matter exists as plasma, which is a gas of ions. The gaseous atoms are heated enough that the electrons are stripped form the atoms.

inverse square law: this refers to any force where the effects are inversely proportional to the square of the distance.

Nuclear fusion

Fusion requires the Collison between two naked nuclei, so in order for this to occur the reactants must be at a high enough temperature to be a plasma, where the atoms are provided with enough energy for the electrons to leave their orbits. In the core of the sun the temperature is estimated to be around 15×10^6 k. at this temperature hydrogen nuclei collide with enough force that the distance between them is reduced enough that the electrostatic repulsion between them is overcome by the strong force by way of **quantum tunneling**. essentially the sun isn't hot enough for nuclei the be close enough to breach the coulomb barrier but since nuclei are quantum objects it is possible though improbable that two nuclei happen to be close enough for fusion, at a temperature below the coulomb barrier.





The sun is so massive (it contains 99.8% of the matter of the solar system) that these unlikely interactions happen all the time, on earth however since we could never produce large enough amounts of plasma for significant enough amounts of energy to be produced from fusion, we have to reach temperatures of around 150×10^6 k. once two nuclei collide in this way, a new heavier nucleus is formed, and often a neutron is ejected as well although this depends on the reactants. Although the new nucleus is heavier than either original nuclei, the total apparent mass of reactants is slightly more than the total mass of the products. The difference between these two is known as the mass deficit and the mass lost is converted into energy in accordance with $e = mc^2$. in the reaction between deuterium and tritium the energy is present as kinetic energy, and future reactors will have to convert this into electricity.

Mass deficit and energy release

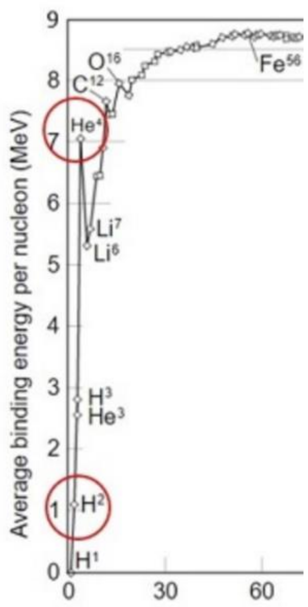
The mass of a nucleus is always slightly less than the mass of its separate components. Before aiming for an explanation, I will first prove it using as an example the alpha particle:

M=0.03035 u   1u = 1.66054×10^{-27} kg M=5.039$\times 10^{-29}$ kg   e=mc^2 =5.039$\times 10^{-29} \times (3 \times 10^8)^2$ =4.535$\times 10^{-12}$j   which in electron volts = 28.3 MeV

An alpha particle consists of two neutrons which each have a mass of 1.00866 amu and two protons of mass 1.00728 amu , to produce a combined mass of 4.03188u. However, experimentally the mass of an alpha particle is found to be 4.00153amu. the mass deficit here is therefore 4.03188-4.11153 = 0.03035 u. this mass deficit represents the amount of energy that would be released if the four nucleons came together:

Therefore, it is also a measure of the amount of energy needed to completely separate the nucleus into its constituent parts. The more energy this requires the more stable the nucleus is. This energy is referred to as the binding energy, and is often converted to binding energy per nucleon which is just the binding energy / the number of nucleons. The mass defect or binding energy is caused by the fact that the strong force overcomes the electrostatic force at a close range. This is very similar to what happens in fusion reactions:

When a nucleon is added to a nucleus it is bound by the strong force to all other nucleons, but primarily to its neighbors due to the short range of the strong force. Binding energy per nucleon increases with the size of the nucleus until a limiting value at around a diameter of 5 nucleons. This is because larger nuclei have a lower surface area to volume ratio. Nucleons near the centre of the nucleus have more neighbors so feel a stronger binding force, so the lower the surface area to volume ratio the stronger the binding force per nucleon as there are more nucleons which aren't on the outside.

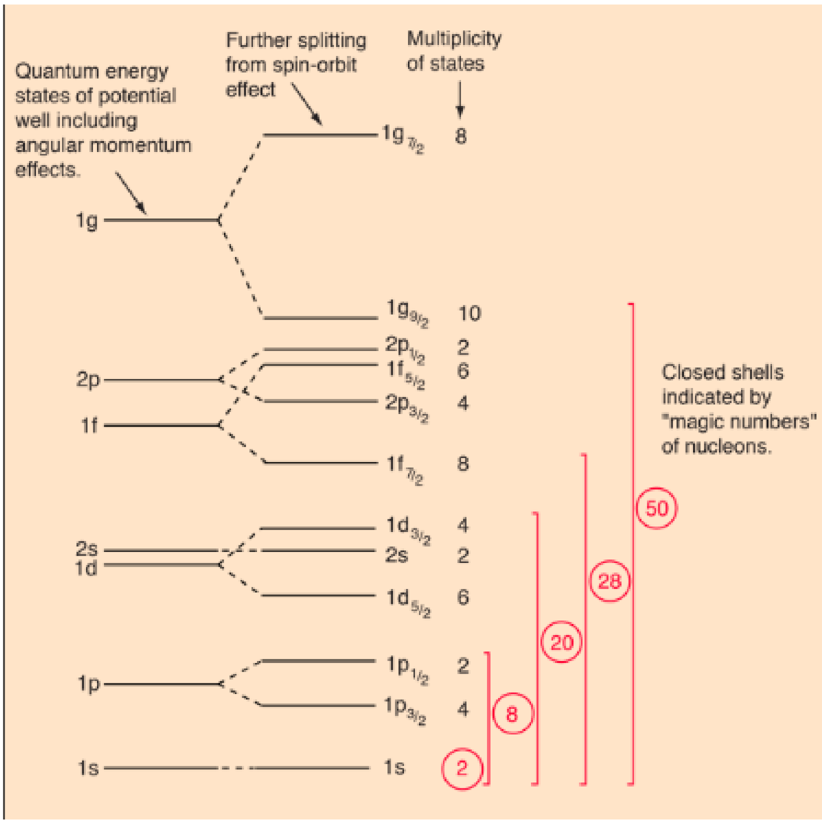


The red circles show the binding energy of the isotope per nucleon

Graph showing the peak in binding energy per nucleon at around Fe 56, and the extraneous value for He 4 source: Matthew Bergstresser

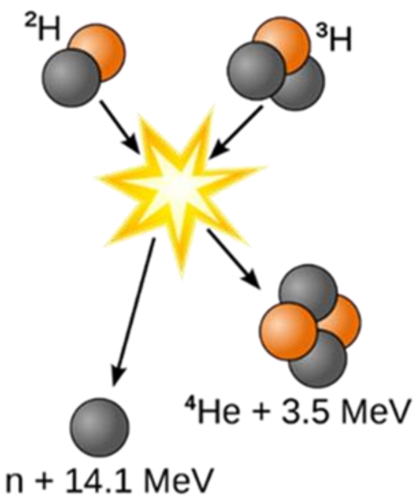
The electrostatic force or coulomb force, is an inverse square force which means it has no limiting range and so as a nucleon enter a nucleus it will feel repulsion from ALL other protons, meaning that the electrostatic energy per nucleon increases without limit as nuclear size increases.

As protons are made of fermions (two up and one down quark), they also have a spin of 1/2. In order to calculate the spin of a nucleus several physicists came up with the nuclear shell model, similar to the shells in which electrons "orbit" the nucleus. It seems absurd that nucleons (protons neutrons) could complete orbits without interacting with each other. However, they behave in ways which obey the pauli exclusion principle. Which means that they must exist in discrete energy levels. Each energy level is given a spin number and each level (except s) is split into two possible spin numbers where the higher spin number is filled first as it has a lower energy, and the lower spin is number is ½ less than the higher one. Protons (neutrons are the same but deal with them separately) fill each level with alternating spins so that they obey the exclusion principle and each level can take 2s+1 protons where s is the spin number of that shell. So for a hydrogen nucleus which only has one proton it has spin of ½ as it has one proton in the 1s orbital. A deuterium ($_1{}^2h$) nucleus has one proton with spin ½ and one nucleus with spin ½ so has a net spin of 1. What this means for helium is that it can have all four nucleons in the ground sate, one spin up and one spin down proton, and one spin and one spin down neutron. This is referred to as a double magic nucleus.



Therefore, the limiting value for binding energy per nucleon is at around Fe and Ni, above this and the total electrostatic repulsion becomes gradually larger than total strong force until a value of negative binding energy is reached for nuclei heavier than Pb. These nuclei are therefore more likely to undergo nuclear fission. An exception to the general trend is He 4. This has a much higher binding energy than expected and this is because it can have all four nucleons at ground state. Which means it has all nucleons at the lowest possible energy state, and it has the most amount of nucleons to allow this possible, meaning it has a very high binding energy per nucleon, which is why helium is of a product of nuclear fusion.

In order for fusion to occur experimentally the coulomb force must be overcome as the volumes of plasma we could produce are not enough to rely on the effects of quantum tunneling. it is smallest for isotopes of hydrogen, (as they have the lowest charge) so lesser temperatures are required. The fusion of tritium and deuterium (D-T fusion) is found to have the highest reaction rate at the lowest temperature than other reactions considered for nuclear fusion like deuterium-deuterium fusion or deuterium-helium 3. The coulomb barrier of D-T fusion is found to be 0.1 MeV (see below). the energy released by fusion can be found as follows: the mechanism for the reaction is as shown in the diagram, where an unstable intermediate of He5 is produced, which immediately decays into a He4 with recoil energy of 3.5MeV and a neutron with kinetic energy of 14.1MeV.



$D_2 + T_3 \Rightarrow H_e + \cap$ where n is a neutron. The mass of reactants is:
(D)2.013553+(T)3.016049=5.029602u
The mass of the helium and neutron is: 4.001506+1.008665 = 5.01071u the mass defect here is of 0.019431u =3.227X10^{-29}kg which equates to an energy released of: M X C^2= 2.904X10^{-12}j=**17.58 MeV**

The energy released is due to the difference in binding energy in the two nuclei, as discussed helium 4 has a very high binding energy meaning it is very tightly bound in comparison with the hydrogen isotopes. Since the helium nucleus has a higher binding energy it must have a lower apparent mass. It is the loss in mass which is what generates such high energy. For reference in the fission of uranium 235 around 200MeV are released, giving an energy of 0.85 MeV per nucleon, whereas in D-T fusion it is 3.52MeV per nucleon.

Equation 1:
V= coulomb barrier
Z=charge in coulombs of nuclei
R= nuclear radius
$4\pi\varepsilon_0 = \frac{1}{K}$=1/8.89876X10^9

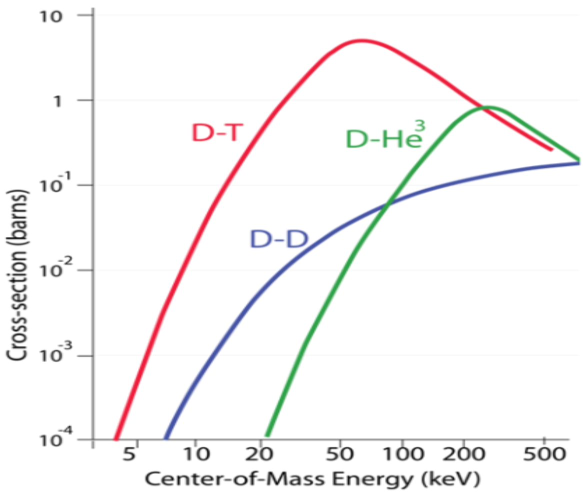
$$V_C = \frac{e^2}{4\pi\varepsilon_0}\frac{Z_a Z_b}{R_a + R_b}$$

Choice of fuel

I have mainly focused on the fusion deuterium and tritium. Evaluation of which fuel to use is done on the basis that we want to primarily focus on the lowest temperatures possible for a reaction to occur. Therefore, a more sophisticated method than that used to calculate the coulomb barrier is used where the probability of a fusion reaction to occur is modeled as a cross section, which takes into account the probability of tunneling which increases as the energy of the particle increases, but in accordance with a Maxwellian distribution, there are less of these particles. Also the effectiveness of a collision depends on the relative velocities of two particles (i.e. a glancing blow between two high speed nuclei isn't as powerful as a head on collision of two slower nuclei) so an average velocity is calculated.

Calculating the coulomb barrier:
The coulomb barrier is simply the amount of energy required to make two nuclei become close enough for the strong force to overcome the electrostatic repulsion.
It can be found using the equation $u = \frac{ke^2}{r}$ where u is the energy required. And r is the distance where the strong force can overcome the coulomb force, k is the coulomb constant and e is the proton charge.
If the distance r is not known we can use equation 1($\varepsilon_0 = permitivity\ of\ free\ space$). The radius of the nuclei must first be found using the fermi model which assumes spherical nuclei with essentially constant charge density:
$r = R_0 A^{\frac{1}{3}}$ where R_0 is 1.2 X 10^{-15} and A is the mass number.
So for a tritium (1 proton 2 neutrons) nucleus the radius =
$1.2 \times 10^{-15} \times 3^{\frac{1}{3}} = 1 \cdot 731 \times 10^{-15}$m
And of tritium =1.512$\times$ 10^{-15}m (4s.f)
Therefore, the value of V_c=7.1149X10^{-14}J (using unrounded values)
Note that this is the energy of each individual particle and that the energy dissipated in the collision will be twice as large.
The temperature required to achieve such temperatures can be calculated using the ideal gas equation:
$k_e = \frac{3}{2}kT$ where K is the Boltzmann constant, giving a temperature of:
$\frac{2\times 7\cdot 11489\times 10^{-14}}{3\times 1\cdot 380\times 10^{-23}} = \mathbf{3.436 \times 10^{\ 9}}$**K**
However, this model is not perfect as fusion can be initiated by nuclei which are out of the Maxwellian distribution, as well as by nuclei under the coulomb barrier by quantum tunneling, furthermore this equation uses the standard radius of the nucleus but the strong force has effect well outside of this radius. As a result, the actual required temperature is found to be at around **0.150X10^{9}K**

The results are presented in the graph shown which demonstrates that the D-T peaks at a lower temperature than the alternative reactions (see graph).



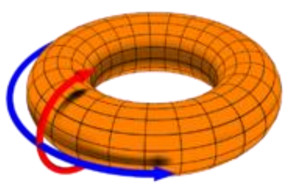
Graph of the cross section to energy of the three possible fuels for nuclear fusion fuel source: NRL Plasma Formulary, 2006 revision

Fusion reactors

Since D-T is considered the most viable fuel source for now the conditions for fusion are as follows:

Around 150,000,000K, a vacuum so that the plasma doesn't interact with any extra matter, large enough volumes (or high enough densities) for substantial amount of collisions to occur, and a long enough suspension time of plasma for collisions to occur in. currently the world's largest nuclear fusion project is ITER in the south of France. It has a budget or around $6 billion and is a multinational attempt to prove that more energy can be released from nuclear fusion than requires to produce it (on earth), this is the so called breakeven point. A value of Q has been used to describe the breakeven point it is a ratio of energy input to output, with the current world record held by the JET tokamak reactor with a Q of 0.67 (this is still below breakeven, values of Q>1 are what is desired) so far two types of fusion reactors are under consideration – thermonuclear fusion and inertial confinement fusion.

Tokamak-thermonuclear fusion



Toroidal axis is the blue arrow, and poloidal axis is the red arrow.

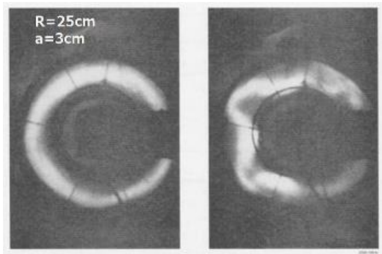


Image demonstrating kink instability, source: Alan Sykes, UK Atomic Energy Authority

One of the biggest challenges in fusion research is the control for long enough durations of plasma. Since plasma is made up of positive nuclei and free electrons, it can be held within a magnetic field by the pinch effect. A central transformer in the "hole" of the toroid induces a current in the plasma (on the toroidal axis), the movement of charged particles induces a ring or magnetic field lines around the circular current (on the poloidal axis), which compresses the plasma. the work done increase the kinetic energy of the charged particles, and the current does as well through ohmic heating, so that the temperature of the plasma is raised, further heating is required (see below). Additional coils on the poloidal axis induce circular field lines on the toroidal axis, this causes the plasma to circulate around the ring, in the same direction in which it is already flowing. These additional outer coils were added and induce a field much stronger than that induced by the current in the plasma due to "kink instability" in the plasma. this is where the plasma ring would shift its centre of mass which resulted in plasma coming into contact with the outer edges of the toroid, inducing heavy metal ions into the plasma, which lowers the temperature of the plasma (sputtering). the additional outer rings helped stabilize the plasma as the superposition of the two toroidal magnetic fields results in a slight tilt of orbit. This means that particles can travel on the inside and then the outside of the ring in the same cycle (see image right).

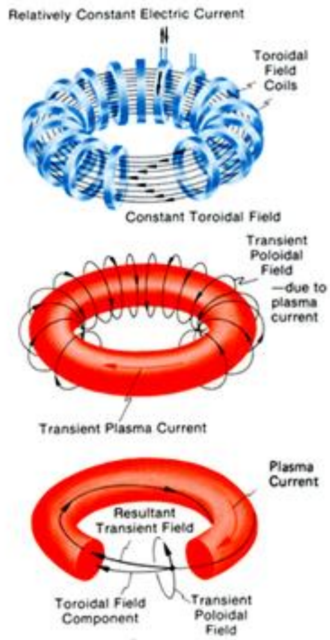


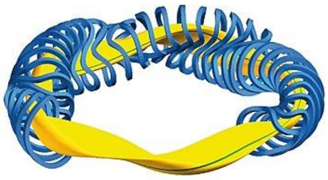
Image showing the result of the superposition of the two poloidal (induced by current) and toroidal (produced by electromagnets) on the orbit of plasma.
Source: http://www.fusionscience.org/technical/ASslides/ASslides.htmlfusionscience.org

The central transformer is kept however as the poloidal coils produce a magnetic field that is stronger on the inside than on the outside of the toroid which would cause particles to drift either up or down, outside of their orbit. It is this vertical drifting which is exploited to produce the tilt in the orbit of the plasma, as described above. In order to heat the plasma beyond the temperatures produced by ohmic heating, two additional sources are used; neutral beam injection and high frequency e.m waves. Neutral beam injection consists of accelerating charged deuterium (for plasma purposes) in a particle accelerator to energies of 1 MeV, and then re-neutralising it by passing it through a gas before injecting into the plasma where it collides with the particles delivering its energy.

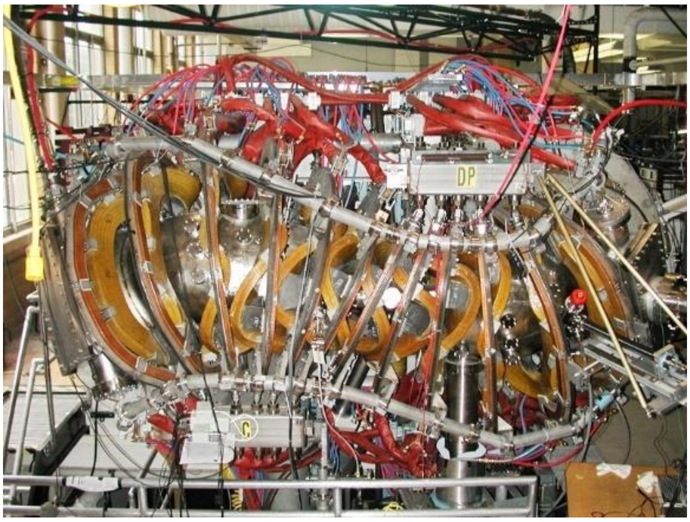
The high frequency e.m waves work in the same way as a microwave, only here a frequency of 40-55MHz is used, this may seem like a very low frequency for e.m waves, but it is made to correspond with the resonant frequencies of the ions inside the plasma, to heat them up faster. These beams of e.m radiation can be fired more precisely to counteract emerging instabilities in the plasma.

Stellarators

These provide an alternative solution to kink instability. Here the complex geometry of the Stellarator means that the magnetic fields produced by the poloidal coils are not any stronger inside the ring than outside, and that particles orbit both on the outside and inside of the ring in the same cycle. This solution is seen as not perfect as some drift still occurs but could provide long enough suspension times for fusion. The drawbacks are that the complex geometry makes it more complex to produce in real life.

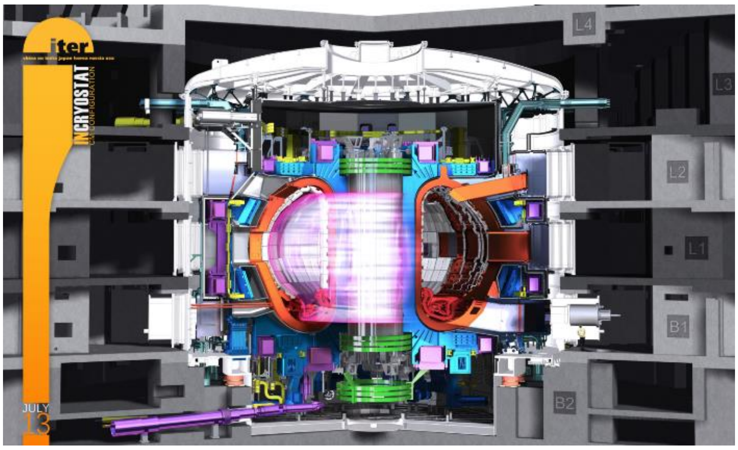


Mathematical stellerator shape (source: Max-Planck Institut für Plasmaphysik)and below the HSX stellarator (source the HSX team)



ITER

ITER is the world's largest **tokamak** with a volume of around 840m^3 of plasma at 150,000,000k and a density of around 1 mgM^{-3} and is supposed to achieve a q of 10 by completion. The tokamak will be designed to output 500 MW of power from an input heating power of 50 MW, it is however only designed to prove the principle is possible, and so will not collect the output as electricity for the grid. However, it does have a water cooling system on the outside of the shell which will use the steam produced to produce electricity and measure power output. Furthermore, it will demonstrate the possibility of tritium production within the fusion chamber, something which is crucial to future fusion reactors as an estimated 20kg of tritium are available on earth today, a lot of which is in nuclear warheads. As mentioned this uses a thick lithium blanket to absorb some of the high energy neutrons which are ejected in fusion reactions (as neutrons are not electrically charged they are not contained within the magnetic field of the tokamak). See image right for the mechanisms. The first of which is favored as it is exothermic and so will increase the temperature of the plasma, it is found that the last two mechanisms have a lower cross section (are less likely to occur) at higher neutron energies so heavily enriched (>80%) Li $_6$ samples are considered for use.



Computer Image of the ITER tokamak reactor
Source; ITER.org

Furthermore, the reaction produces one tritium atom per neutron absorbed, so neutron multipliers will be used (see image right). exact workings of these lithium blankets are not finalized, but will take the form of large sections inside the reaction chamber, which is made up of 440 1 X 1.5m modules of around 4.6 Tonnes each.

$$^{6}\mathrm{Li} + \mathrm{n} \rightarrow \alpha + \mathrm{T} + 4.78\,\mathrm{MeV} \quad (E_{th} = 2.47\,\mathrm{MeV}),$$

$$^{7}\mathrm{Li} + \mathrm{n} \rightarrow \alpha + \mathrm{T} + \mathrm{n}' - 2.47\,\mathrm{MeV},$$

$$^{7}\mathrm{Li} + \mathrm{n} \rightarrow 2\mathrm{T} + 2\mathrm{n}' - 10.3\,\mathrm{MeV},$$

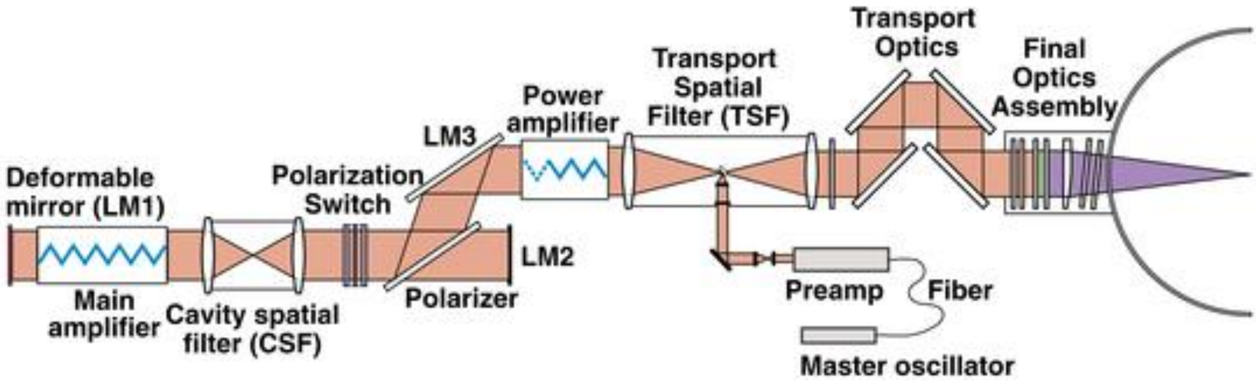
$$^{9}\mathrm{Be} + \mathrm{n} \rightarrow 2\alpha + 2\mathrm{n}' - 2.5\,\mathrm{MeV} \quad (E_{th} = 2.7\,\mathrm{MeV}),$$

$$^{208}\mathrm{Pb} + \mathrm{n} \rightarrow {}^{207}\mathrm{Pb} + 2\mathrm{n}' - 7.4\,\mathrm{MeV}.$$

(top) tritium breeding mechanisms from lithium (bottom) neutron multiplying mechanisms using lead and beryllium source: Fusion Neutrons: Tritium Breeding and Impact on Wall Materials and Components of Diagnostic Systems-Mark Rubel

Inertial confinement fusion

In ICF the fuel is a pellet containing a deuterium-tritium core of around 10milligrams. The outside is shot with high powered laser beams, or ion/electron beams from all sides.



Sim
source : Science and Technology Review, July/August 2007

The result is the explosion of the outer layer, the shockwave of which is sent towards the center of the pellet, amplifying the compression wave as it moves inwards to compress the core, to around 230 kgM^{-3} and 100,000,000k resulting in fusion. The most notable example of such a reactor is the NIF which uses 192 lasers to concentrate energy onto the fuel pellet. Lasers are used in preference to particle accelerators due to the uniformity of energy required to create a shock wave which properly travels towards the central point of the pellet. The aim of the project is to result in complete combustion of the pellet, a process which can only occur if the high energy alpha particles produced from the fusion in the center of the pellet can transfer their energy to surrounding fuel faster than energy is dissipated from the reaction in the form of high energy electrons and x-rays, a condition known as bootstrapping.

The overall proccess is wildely inneficient (see diagram) as such it remains unclear if breakeven will ever be reached, in 2013 a team claimed they had reached it but the comparison was between the approximately 10 kJ that reaches the fuel and the 14 kJ that were produced, a Q of 1.4. however breakeven must be when the fusion output was equal to the laser input this would be 1.8 MJ in and 14 kJ out, a Q of 0.008.

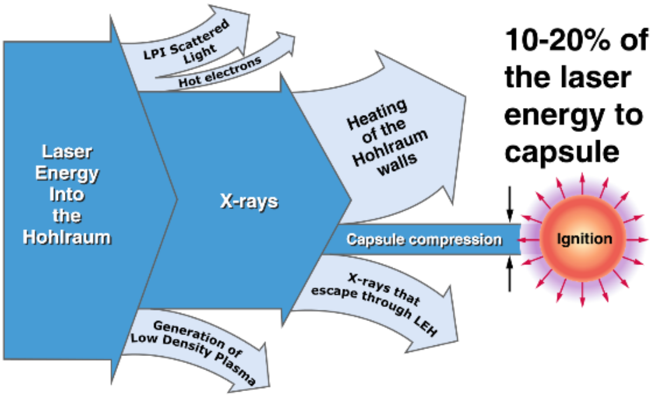
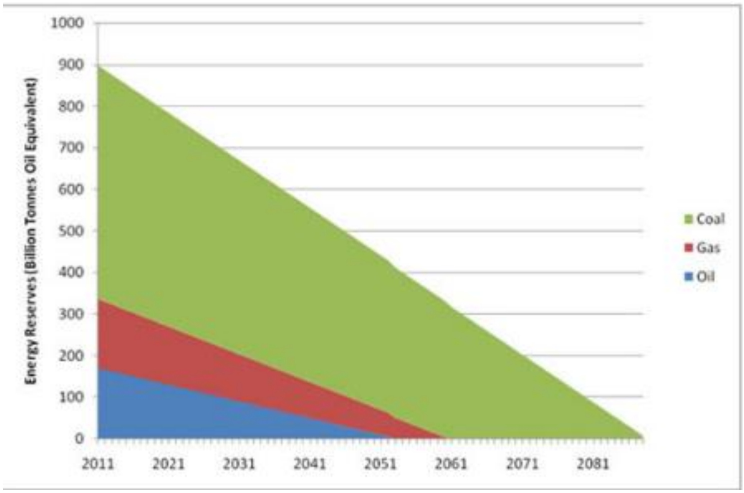


Diagram showing energy losses before absorption into the capsule, note that the laser energy in is after conversion from ir to uv, a process which is about 50% efficient.
Source:
http://www7.nationalacademies.org/bpa/PLSC_Sept05_Presentation_Lindl.pdf

CONCLUSION

It seems unlikely that we can go on for much longer using fossil fuels as a source of electricity, despite this, only around 25% of the earths electrical consumption comes from renewable sources. So it seems certain that we must find an alternative source of energy or risk having to use candles, with the progress which has been I fusion research, an ongoing struggle which has lasted around 60 years. And since many projects have come and gone, but the idea has never been lost, it seems probable that we will see nuclear fusion reactors come into use within the years to come.



Graph showing an estimation for the duration of fossil fuels
Source:ecocitry.uk

The question of when is about as uncertain as the position of a quantum particle with known velocity, ITER claims it will be able to start D-T fusion by 2035, although it has already suffered multiple delays and gone $3B over budget. new projects are emerging such as china's CFETR (China Fusion Engineering Test Reactor) which will begin construction in the 2020's and will aim to demonstrate a SteadyState plasma, followed by tritium breading, until final stages where modifications will be made to allow it to produce 1GW of power with a Q factor of 12.

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COLD FUSION!

In March 1989, spectacular claims were made for another approach to nuclear fusion, when two researchers, in the USA (Stanley Pons) and the UK (Martin Fleischmann), claimed to have achieved fusion in a simple tabletop apparatus working at room temperature! 'N-Fusion', or 'cold fusion', involves the electrolysis of heavy water using palladium electrodes on which deuterium nuclei are said to concentrate at very high densities. The researchers claimed that heat – which could only be explained in terms of nuclear processes – was produced, as well as fusion by-products, including helium, tritium and neutrons. Other experimenters failed to replicate this, however, and most of the scientific community no longer considers it a real phenomenon.

DYLAN WILKS 13P

ELASTIC AND INELASTIC DEFORMATIONS AND COLLISIONS

Mathematical Observations of a Collision

By definition impulse is given by the following equation:[1]

Fig 1.1

$$\int_{t_1}^{t_2} F(t)\, dt$$

Fig 1.1 represents the area underneath a force with respect to time graph from times t_1 to t_2. Intuitively, this area represents the overall varying force acting on an object over a given time frame, implying a changing velocity during said time period.

It can be proven that the integral can be broken down into the difference in momentum of the object during the time period of the acting force:

Fig 1.2

$$\int_{t_1}^{t_2} F(t)\, dt = mv - mu$$

$$\Longrightarrow mv = \int_{t_1}^{t_2} F(t)\, dt + mu$$

Where *m* represents the objects mass and *v* and *u* represent final and initial velocity respectively. This allows for a method of computing the impulse without knowing the actual values of the force and the time for which it acts.

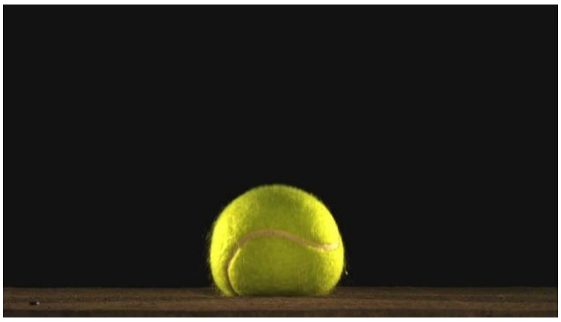
The second part of Fig 1.2 is included for the sake of intuition as it basically implies that the new momentum is equal to the resultant of the impulse and the initial momentum, showing direct influence of the impulse.

Another fact that can be derived from this equation is that regardless of how large or small the difference between the force and time frame is, given an initial momentum, if the impulse is to remain the same value for all these variations the final momentum will always be the same.

During a collision between a set of objects forces will be present against all of them. This is the result of Newton's first law, which states that if there exists a rate of change in velocity then there follows along a force acting on the object(s). Based on observations and experience it is clear that when a collision occurs said objects undergo a change in velocity, which implies a non-zero acceleration and hence a force.

Similarly, using Newton's third law, which states that for every force acting in a direction there exists another equal force in the opposite direction, we can infer that every object in a collision experiences the same force.

The elasticity of objects is what results in the collisions lasting for a certain period. Every object experiences some form of deformation when forces are present against it: this deformation is what causes the objects to stay in contact for some time, and hence allowing for an impulse to exist.



This ball is being deformed due to the force acting on it when it collides with the floor. It bounces back up by using its own body against the floor when reforming to its original shape.

If the object is able to regain some or all of its former shape after deformation it will exert a force in the opposite direction by pushing back, and hence a force acting back on it as a result of Newton's third law.

This force exerted on the object is representative of the overall sum of the forces acting on it. The existence of these forces is due to Newton's first law as stated before, but the more interesting bit of detail is how the overall sum varies overtime and why deformation occurs in the first place. It is mainly due to inertia and the object's structure.

The individual forces act on the material points(1)[2] of the object. Once the object collides with a surface the points of contact will suddenly halt (if viewing relative to the surface), but the rest of the object will continue moving

(1) *'Material Point': Typically, when treating collisions at a school level the objects are treated as point-masses; they are mathematical abstractions that do not exist in real life. They are abstractions in the sense that they are treated as just a 'point', no dimension or size.*

Realistically, objects have both a dimension and a size, which are built up from smaller elements that have mass. These smaller elements are known as material points. Note that these elements are not typically referring to atoms or molecules as they are too small and Newton's laws are not intended for such a small scale.

forward. As a result, the object will compress by moving inward on itself. This is possible as every material point of an object is endowed with some inertial mass, meaning they have a tendency to continue moving in the original direction.

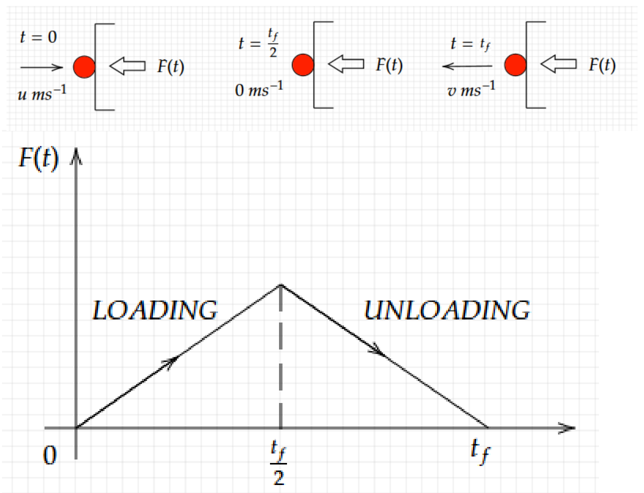
When the entire object balances in speed, compression will cease and hence will begin to reform its shape, and by doing so it will exert a force back on the surface and begin to move in the opposite direction.

The variation in the overall force is the result of each material point experiencing a different force at different times. This is because of both the inertial mass of individual material points and the structure of the object; restoring forces act to reform while inertia and the impact forces work together to cause deformation. Note that this overall force acts on the centre of mass of the object.

A Model for Perfectly Elastic Collisions[3]

Perfectly elastic collisions result in all the objects involved in a collision to regain their complete former shape after deformation. As a result, the object will be moving away at the same speed as it had upon impact.

Fig 2.1



The reason behind the shape of this graph is based on Hooke's Law and the fact that the restoring forces between the atoms is proportional to their separation distance.

Fig 2.1 assumes a perfectly elastic collision between a ball and a wall lasting from times $t = 0$ to $t = t_f$. Hooke's law(2) is obeyed throughout this entire period. In this model we are assuming the wall is infinitely big and completely rigid and hence does not move nor deform. No external forces exist.

Upon impact with the wall the ball is initially moving at u ms^{-1}. The ball undergoes some deformation (loading), and at $t = t_f/2$ the ball is the most deformed it can be for this model and is now moving at 0 ms^{-1} against the wall. After this point the ball attempts to return to its former shape as no forces are working against it to further deform it (unloading), and thus it exerts a force against the wall when reforming and thus on itself. When completely reformed no more forces are present and the ball moves away at v ms^{-1}. It should be noted that as this model is perfectly elastic $v = u$.

For easier mathematical analysis of the collision the function can be abstracted into a single line.

Fig 2.2

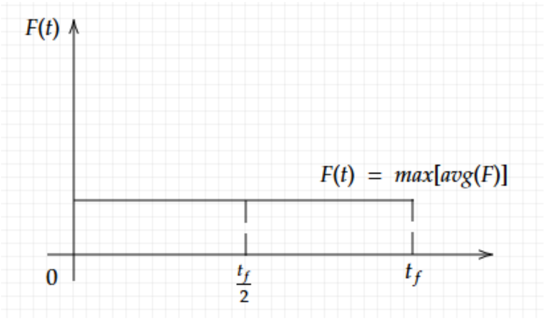


Fig 2.2 represents a single value of *F(t)* which is the average force of the model in Fig 2.1. This force acting against the ball for the entire time period still results in the same output; the ball stays in contact with the wall for the same amount of time and moves away at the same speed.

It can be derived that the constant/average *F(t)* value must be the maximum average force possible for a given time frame of the collision. A maximum exists due to limitations stated by the *law of conservation of energy;* if *avg(F)* were any greater this law would be violated as the ball would be moving away faster than it were approaching: the system has *gained* more energy from nothing.

Using this abstracted model several facts can be derived:

Fig 1.3

$$(1) \qquad max[avg(F)] \implies max\left(\frac{dv}{dt}\right)$$

$$(2) \qquad max[avg(F)] = \frac{2mv}{t_f}$$

Equation (1) from Fig 1.3 states that the average rate of change of velocity is also a maximum given that the average force is a maximum. This makes sense as $F = ma$, which implies that $max(F) = max(ma)$. But as m is typically given for a model, we can say that $max(ma) = m[max(a)]$. By transitivity the limitations on the force given by the conservation of energy law also apply on the acceleration.

Equation (2) shows an identity for calculating the absolute maximum average force of a perfectly elastic collision, where v is the velocity of the object upon collision or when moving away, m is the mass of the object and t_f is the time duration of the collision. This identity can be proven using the equation in Fig 1.2.

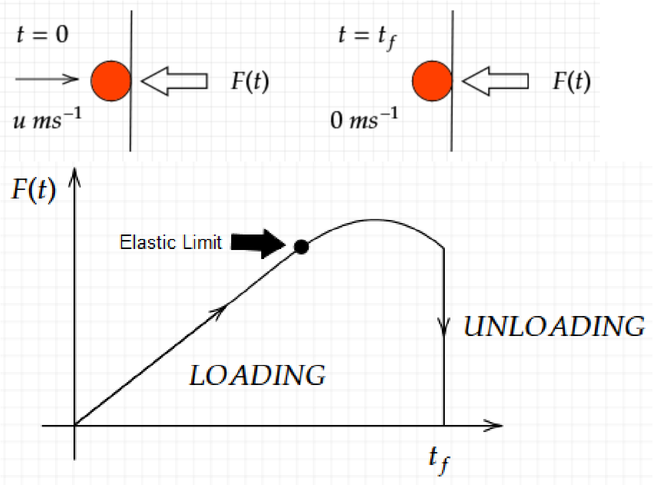
---

(2) *'Hooke's Law': this is a region of the object where its restoring/driving force is proportional to the extension. If the object remains in this region it will always undergo elastic deformation. Note that sometimes objects do not need to obey Hooke's Law for elastic deformation.*

A Model for Perfectly Inelastic Collisions[4]

Perfectly inelastic collisions result in the objects involved in a collision to lose all sense of their former shape after surpassing their elastic limit(3): they stay permanently deformed. Consequently, this means that they will not be able to push themselves away, instead they will 'coalesce', or attach to whatever they have collided with. Relative to a certain point of view(4) this also means that at the end of the collision the object will end up moving at $0\ ms^{-1}$, or more generally the system experiences a maximum loss of kinetic energy.

Fig 2.3



This force only works on slowing the ball to 0 ms⁻¹; deformation occurs the entire time after the elastic limit without any reformation. The reasoning behind this shape is based on the structure of the atoms.

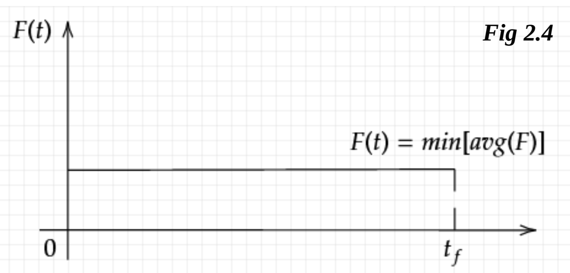
Fig 2.3 assumes a perfectly inelastic collision with similar conditions to those in Fig 2.1, with the exception that the ball undergoes inelastic deformation past the elastic limit.

The ball undergoes similar events to those in the model in Fig 2.1, the difference being that at the end of the collision the ball is moving at $0\ ms^{-1}$ and the force against time graph takes a different form. As soon as the ball stops compressing at time t_f forces cease to act on it, hence coalescing with the wall. No impulse is present for reforming.

It is shown in the graph that the object has an elastic limit. Depending on the initial velocity and nature of the object, the extension may or may not have surpassed this threshold and thus could have resulted in a perfectly elastic collision instead

Much like the abstraction in Fig 2.2 for perfectly elastic collisions we can do the same for perfectly inelastic collisions:

Fig 2.4



The notable difference between Fig 2.2 and Fig 2.4 is that perfectly elastic collisions have a maximum whilst perfectly inelastic collisions are at a minimum for the given time frame.

Through this abstracted model similar facts to Fig 1.3 can be derived:

Fig 1.4

$$(1)\quad min[avg(F)] \implies min\left(\frac{dv}{dt}\right)$$

$$(2)\quad min[avg(F)] = \frac{mv}{t_f}$$

Equation (1) from Fig 1.4 states that the average rate of change of velocity is also a minimum given that the average force is a minimum. If the acceleration were to be any lower then this would imply that the ball would keep moving against the wall at the end of the collision, which doesn't make any sense.

Equation (2) shows an identity for calculating the absolute minimum average force for a perfectly inelastic collision, where v is the velocity of the object upon collision, m is the mass of the object and t_f is the time duration of the collision. Much like before this identity can be proven using the equation in Fig 1.2.

A Model for any Collision[5]

Some collisions may have it so that some of its former shape is restored after inelastic deformation. In this case the kinetic energy lost is neither a maximum nor a minimum as stated before. This also means that the objects will rebound against each other, they will not coalesce.

To understand how to create such a model we will use what is known as the *coefficient of restitution*[6], a constant ratio that is typically denoted by the letter *e*. Newton's experiments led him to derive this law of impact, which

3) *'Elastic Limit': the elastic limit is defined as an object's threshold for strain (ratio of extension against original length) which creates the boundary between elastic and inelastic/plastic deformation. In other words, if the object is stretched beyond this point it will become permanently deformed.*

It is worth pointing out that even after undergoing stress past this threshold some materials will be able to recover some length; they are able to partially reform. However, if the material undergoes ***perfect*** *inelastic deformation - which occurs in perfectly inelastic collisions - then the object will not be able to recover any length at all.*

(4) *'Relative to a certain point of view': Generally, in a perfectly inelastic collision the loss of kinetic energy is said to be a maximum. Sometimes the final kinetic energy may not be 0J after a collision; however, if observed relative to the centre of mass of the entire system the resultant kinetic energy at the end of the collision is then 0. This is the result of some mathematical analysis on the net momentum of a system and its centre of mass.*

states the following:

Fig 1.5

$$ev_a = v_s$$

$$\implies \frac{v_s}{v_a} = e$$

Where *e* is the coefficient of restitution, v_a and v_s are the speed of approach and separation between 2 objects respectively. Note that *e* is dimensionless.

As we are talking about speed of approach and separation, we need to regard these values when moving relative to at least one of the objects. Assume the following model:

Fig 2.4

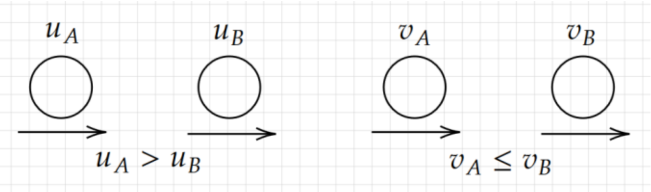


Fig 2.4 shows a collision between 2 balls and their velocities before and after. The speed of approach regards the moment before the collision while the speed of separation is after it has happened. To obtain v_a we have to move relative to the object moving at u_B ms^{-1}, and for v_s we move relative to the object moving at v_A ms^{-1}. Doing this we get the following set of equations:

Fig 1.6

$$(1) \quad v_a = u_A - u_B$$

$$(2) \quad v_s = v_B - v_A$$

From these equations it is visible to see that the speed of separation will always be less than the speed of approach. Using this idea and Fig 1.6 we can derive the most astounding fact about the coefficient of restitution: its values lie between 0 and 1.

This is an incredibly useful fact in the sense that it tells us how much deformation has occurred in a collision. A value of ‘1’ tells us that the collision is perfectly elastic, ‘0’ tells us that it is perfectly inelastic, and any other number means some length has been recovered after inelastic deformation. Using transitivity again we can apply this same concept to the kinetic energy lost in a system.

Keep in mind that the fundamental reason for these boundaries is due to the conservation laws of energy.

We can now construct a model using this constant that is general to any sort of collision:

Fig 2.5

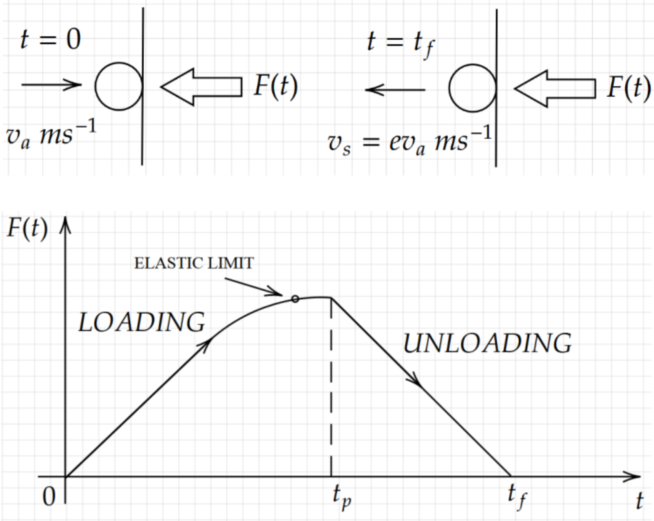


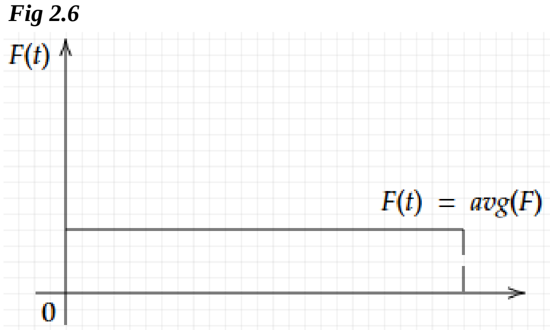
Fig 2.5 assumes a model with the exact same conditions as those for Fig 2.3.

Using the equations from Fig 1.5 we can find out the velocity of the ball after the collision given *e*. We can see how this links in with the previous 2 models: if $e = 1$ then the velocity of the ball would remain the same: the collision would be perfectly elastic. Otherwise, if $e = 0$ then the velocity of the ball would be 0, implying a perfectly inelastic collision.

If any object were to surpass its elastic limit then *e* will always be less than 1. The graph shown in Fig 2.5 models a collision that is neither perfectly elastic nor inelastic. It is quite clear that the impulse acting to reform the object is smaller than the impulse for deformation (acting until time t_p), thus hinting at the idea that the object is able to restore only some of its former shape.

Once again, we can abstract this model to receive the following:

Fig 2.6



This average force will be inclusively bounded between the maximum and minimum averages possible. One equation we can derive from this is the following:

Fig 1.7

$$avg(F) = \frac{(1+e)mv}{t_f}$$

Where e is the coefficient of restitution of the collision, m and v are the mass and velocity of the object upon collision respectively and t_f the time of the collision. You can see how this more general equation for the average force links with the special cases in Figs 1.3 and 1.4.

Additional Mathematical Observations[7]

A major factor in collisions that has not been regarded much is that of energy. By using the laws of energy, we are able to derive many more equations and explain certain phenomena in our observations.

To derive equations related to the velocities of a one-dimensional collision given any relative motion of the viewer we need to use the laws of energy and consider the *conservation of momentum law*. Recall that using Newton's third law we can infer that in a collision between 2 objects both objects receive equal impulses. Consequently, using the identity in Fig 1.1 we can say that they experience an equal increase in momentum in opposite directions. The directions matter as momentum is a vector quantity, and thus the overall sum of this increase in momentum is zero.

What this means is that for any collision there will be no change in momentum. Simply put the momentum of the system before and after the collision will remain the same. And from this we have our law using the following model:

Fig 2.6

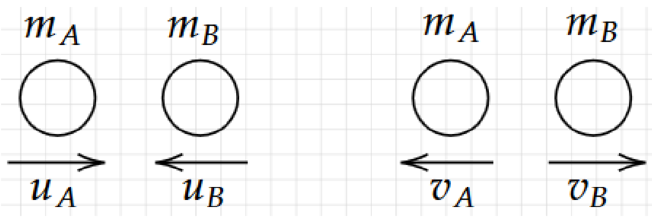


Fig 1.8

$$m_A u_A + m_B u_B = m_A v_A + m_B v_B$$

Where m_A and m_B are the masses of the objects, u_A, v_A, u_B and v_B are the initial and final velocities of the first and second object respectively before and after the collision.

To setup an equation for calculating the velocities of 2 objects in a perfectly elastic collision we have to use the idea that both momentum and kinetic energy are conserved.

Fig 1.9

$$(1) \quad m_A u_A + m_B u_B = m_A v_A + m_B v_B$$

$$(2) \quad \frac{1}{2} m_A u_A^2 + \frac{1}{2} m_B u_B^2 = \frac{1}{2} m_A v_A^2 + \frac{1}{2} m_B v_B^2$$

By solving the 2 equations the following identities can be painfully and rigorously proven.

Fig 1.1.1

$$v_A = \frac{m_A u_A + m_B u_B - m_B(u_A - u_B)}{m_A + m_B}$$

$$v_B = \frac{m_A u_A + m_B u_B - m_A(u_A - u_B)}{m_A + m_B}$$

Note that there is a trivial case when both masses are the same; the velocities are essentially just transferred over.

Fig 1.1.2

$$v_A = u_B$$
$$v_B = u_A$$

Solving velocities for perfectly inelastic collisions between 2 objects is much more simple. We can use the idea that in such a collision the objects coalesce, implying that they move at the same speed. In other words, using models Fig 2.6 or 2.4, $v_A = v_B$. Thus, we get the following.

Fig 1.1.3

$$v_{A,B} = \frac{m_A u_A + m_B u_B}{m_A + m_B}$$

When comparing the equations between Fig 1.9 and Fig 1.1.3, it might be evident that there is just a subtle difference. More specifically, there are some missing terms. Notice that Fig 1.1.3 is missing the term $m_B(u_A - u_B)$ or $m_A(u_A - u_B)$.

Based on what we've covered, you might get the idea that the coefficient of restitution could have play here, considering its range and how it relates to the type of collision.

The coefficient of restitution reveals itself when we attempt to solve for a more general equation; solving for velocities from a collision that can be neither perfectly elastic nor inelastic from any frame of reference without acceleration.

Using equations from Figs 1.5, 1.6 and 1.8 we now get 2 simultaneous equations to work with.

Fig 1.1.4

$$(1) \quad e(u_A - u_B) = v_B - v_A$$

$$(2) \quad m_A u_A + m_B u_B = m_A v_A + m_B v_B$$

Solving for the final velocities of the system we now get the following:

Fig 1.1.5

$$v_A = \frac{m_A u_A + m_B u_B - e m_B (u_A - u_B)}{m_A + m_B}$$

$$v_B = \frac{m_A u_A + m_B u_B - e m_A (u_A - u_B)}{m_A + m_B}$$

Looking at this it is now clear where the missing term went. As the collision was perfectly inelastic, the coefficient of restitution, *e*, would be equals to 0 and hence the terms were annihilated.

Collisions and Energy

The following outcomes regarding the kinetic energy of a system can occur in a collision:

(1) *The net kinetic energy of the entire (isolated) system remains constant before and after the collision. These kinds of collisions are known to be* ***perfectly elastic****.*

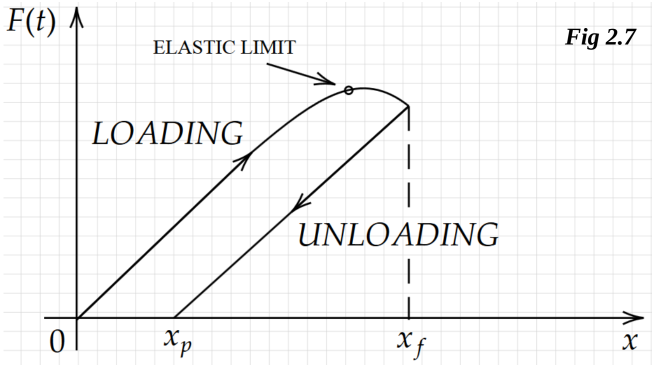
(2) *The system experiences a maximum possible loss of kinetic energy. These collisions are said to be* ***perfectly inelastic****.*

(3) *The loss of kinetic energy in the system is neither the maximum nor the minimum.*

In collisions that aren't perfectly elastic the kinetic energy isn't conserved. However, if we were to use our former models and thus ignore external forces such as air resistance or friction, according to the energy conservation law the net energy does not change in the system.

The kinetic energy lost in a collision under these circumstances is instead converted into potential energy, which is stored in between the atoms or molecules of the deformed object. It is this conversion in energy that causes the object to slow down in the first place during a collision. Some kinetic energy is lost as heat in the process but this is typically negligible.

When calculating the kinetic energy lost in a collision we have to consider the loading and unloading portions of a model. For calculations it would be easier to use a force against time graph because of how the function of force with respect to time is bijective and continuous (for the time it lasts at least), but for intuition or explanation using a force against extension graph would be better.



Notice how the loading line is parallel to the unloading line (up to Hooke's Limit). The gradient at a point represents its overall stiffness at that very moment.

Fig 2.7 represents a force against extension graph for an object undergoing deformation from a collision. It obeys Hooke's law up to a point and experiences inelastic deformation past the elastic limit. The values x_p and x_f are respectively the permanent extension of the object and the maximum extension during deformation.

The work done on an object is given by[8]:

Fig 1.1.6

$$\int_{x_1}^{x_2} F(x)\,dx$$

$$= \frac{1}{2} m \left(v^2 - u^2\right)^{*}$$

Where the first equation is the integration of the overall force with respect to displacement, *x*, between distances x_1 to x_2. The second equation is an identity of the first equation, where *m* is the mass of the object and *v* and *u* respectively represent its final and initial velocities. The displacement in our case means the extension of the object instead.

When talking about the work done on an object from deformation, we are referring to the kinetic energy lost/stored as potential energy during the loading period. For the unloading period we are instead referring to the kinetic energy restored from that stored potential energy.

From the second identity we can see that for the loading period the work done should be negative. This makes sense as the final velocity would be 0, which is smaller than the initial velocity. The object has slowed down and hence lost kinetic energy.

It should be noted that this contrasts to what is shown in Fig 2.7, where the area is positive. This is because it is treating the extension/displacement as an absolute, but realistically the direction of it matters as well. If we were to consider the force to be acting in the positive direction, then

** This identity only holds if both velocities end in the same direction.*

the object would be moving in the negative direction instead during the loading period, and hence a negative work value.

As for the unloading period it would be the opposite. The object is gaining speed and hence has a positive work value.

If we were to sum the values of the work done for both the unloading and loading period our value will lie in the range:

Fig 1.1.7

$$-\frac{1}{2}mu^2 \leq W \leq 0$$

Where *W* is the overall difference in kinetic energy before and after the collision; the kinetic energy lost.

It is easy to see where these bounds come from. The upper bound is the consequence of a perfectly elastic collision. It results in a 0 as the speed of the object is the same before and after, hence no difference.

The lower bound is the result of perfectly inelastic collisions. This is the maximum kinetic energy that can be lost in said collision, and it can be seen why this is the case when referring to Figs 2.3 and 1.1.6.

Note that these values only hold when moving relative to the surface the object will collide with, much like the models in Figs 2.1 and 2.3.

When calculating the difference in kinetic energy using a force against time graph such as the one in Fig 2.5 a different equation (Fig 1.1.8) will have to be used instead.

Fig 1.1.8

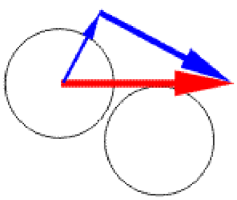
$$\int_{t_1}^{t_2} F(t) \cdot v(t)\, dt$$

Where *v(t)* is the velocity of the object with respect to time.

Collisions in Higher Dimensions

So far only collisions in one dimension have been covered, which is a really specific case that does not appear in real life as much as two-dimensional collisions do.

However, the ideas presented here are generally true, and adapting our equations to higher dimensions is only a matter of considering additional variables such as angles and extending our vectors. They will not be covered here as it is just a case of mathematical analysis.



The Fundamental Cause of Restoring Forces and Inelastic Deformations

It is helpful to have a basic grasp on the inner workings of an object when it undergoes deformation.

Firstly, the obvious needs to be stated: there exists a force acting between the atoms in an object. Based on what has been stated it's clear that that these forces vary depending on the extension of the object, or similarly the distance between each atom.

Before being able to graph this force alongside extension we need to look at the general shape the potential energy takes between 2 bonded atoms given the distance between them:[9]

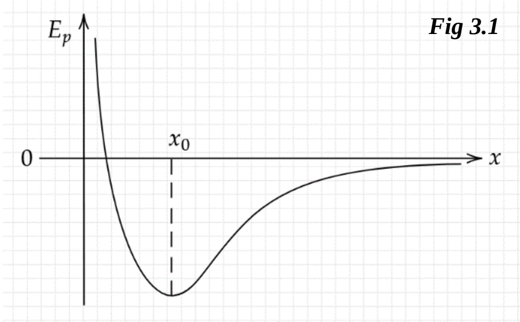


Fig 3.1

The shape of this curve is derived from what is known as the Hamiltonian. However, this topic is beyond our scope.

Fig 3.1 shows a graph of the potential energy E_p against the distance *x* between 2 atoms. The distance x_0 indicates where the lowest state of energy resides; the global minimum. The potential energy is defined to be 0 when the distance between them is infinite.

As there does not exist any metastable states the atoms will tend toward the global minimum at all times, disregarding external forces. When tending towards this equilibrium they will lose potential energy. They bond by losing potential energy.

Recall from Fig 1.1.6 that the work done, or more specifically the kinetic energy *lost* as potential energy is calculated by integrating the force with respect to distance. From this we can instead take the derivative of the work done with respect to distance to get the restoring force:

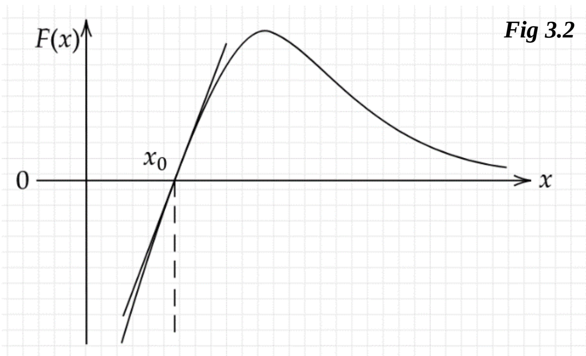


Fig 3.2

The line at x_0 represents the gradient of the function at that point. This is where Hooke's law comes from; the line is a good linear approximation of the forces up to a certain point.

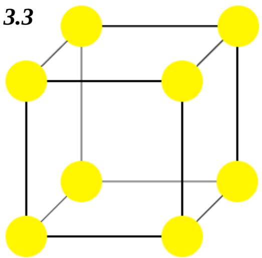
From the graph we can now determine how the forces between 2 atoms behave. If the distance between the atoms is greater than x_0 then the restoring forces will act to bring them closer. If they were smaller than said distance the forces will act to separate them.

And now we can state how some length is recovered after deformation: the forces between the atoms will act to bring them back to their equilibrium state after having been moved away from it. The overall restoring force we observe on a macro-scale is the sum of all these forces.

But how do inelastic deformations happen? How does this concept apply to perfectly inelastic deformations, where no forces act to restore it at all? Clearly something more permanent is occurring. This is where the concept of dislocations come in.

Take a crystalline object for example, such as some sort of metal. The atomic structure will be densely packed, but will be arranged in an orderly fashion as pictured in Fig 3.3.

Fig 3.3

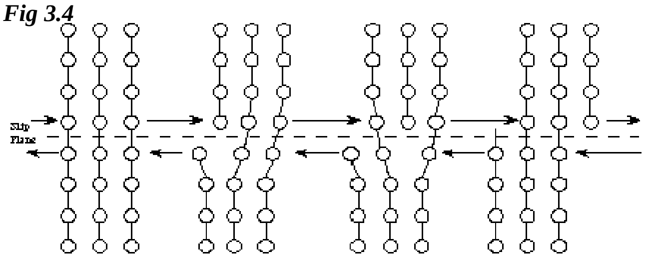


When we deform it by stretching or compression, a *shear* will typically occur between the atoms. This is when layers of atoms will slide past each other. It makes sense for this to occur as some of the atoms would be moving in opposite directions during deformation.

If elastic deformation occurs the atoms will simply shift around a bit along the direction of the shear. Once the external force is removed, they will return to their former configuration.

However, once we pass the elastic limit something else happens. The shearing forces acting on the atoms are great enough to break bonds. As one atom moves further away from its bond another moves in closer and displaces it.

Fig 3.4



During this shearing there are regions of atoms that lose their bonds and do not form new ones. These regions are known to be *'dislocations'* [10]. They are irregularities in the atomic packing, which are the cause of inelastic deformation.

SEE FOLLOWING PAGE FOR ALL REFERENCES

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Mr D'MELLO'S

PUZZLE CORNER

Mr D'Mello has posed 3 brainteasers for us:

1. Would a gas exert a pressure if there are no container walls confining it to a definite space?
2. A solid cube rests on a level surface. The cube is then heated by a large amount. Does the pressure exerted by the cube on the surface INCREASE, DECREASE or STAY THE SAME?
3. Statement from OCR GCSE Physics specification: "3m An understanding of ratios and how this enables gears and levers to work as force multipliers." WHY is a lever a force multiplier? Why does a gear not actually multiply forces (although it does multiply something else)? Can you re-write the statement to make (a bit) more sense.

IF YOU CAN COME UP WITH THE ANSWERS, Mr D'MELLO WILL BE PLEASED TO HEAR FROM YOU!

jdmello@st-benedicts.suffolk.sch.uk

A SPECIAL FEATURE from

Mr A WATTS

We all remember Mr Watts with great fondness and we are happy to report that he keeps in touch and has lost none of his enthusiasm for Science. Mr Watts is a great fan of SCIENCE PODCASTS and has sent us a list of his favourites:

Podcast		**Average length/mins**	**Key stage**	**Try**
Great Moments In Science	Occasional, topic-based Australian, Dr Karl, takes you through science snippets	7	all	Examples are: Beetroot, Cannibalism, Electrostatic spiders
BBC: Inside Science	Weekly broadcast about science	30	4/5	
99% Invisible	Weekly broadcast about technology	30	all	For the love of peat (one for the geographers!), Toilet paper *(history, shortages and how should you use it?),* Hawaiian shirts *(no, do try it!)*
Chemistry World	Does what it says on the tin! The site has articles, videos and sound files.	Varies	4/5	Asparagus wee, Cleaning chemicals, elements *(choose one to hear about).*
BBC: Science In Action	Weekly broadcast about science	30	4/5	
BBC: In Our Time Science	Weekly broadcast with occasional science episodes.	45	4/5	Proton, Dorothy Hodgkin, free radicals, enzymes, feathered dinosaurs
Skeptics Guide To The Universe	Weekly, American perspective, very up to date science broadcast but can be a bit sweary occasionally	90	4/5	Try their latest episode
BBC: More or Less	Weekly broadcast about the numbers in the news. Very insightful.	Varies	4/5	Should you wear a face mask?' *Just what is the science behind this?,* Schools and coronavirus
Science-ish	Occasional, topic-based broadcast that discuses science using the movies.	30	4/5	Deadpool *(will we ever be able to regrow limbs?),* Invisible Man *(Will we ever be able to become invisible?)*
BBC: The Infinity Monkey Cage	Occasional topic-based broadcast that discuses science with Professor Brian Cox and comedian Ince.	30	4/5	The science of fire, Coral reefs, anniversary of periodic table.
Guardian Science	Weekly broadcast about science	15-30	4/5	

Mr Watts was, of course, our resident chemistry expert and has also sent us a couple of fun items: fizzing carbonates and automatic sunglasses – check out the chemistry!

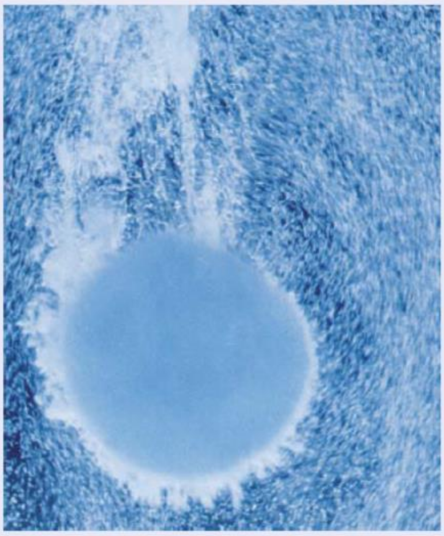
Fun with Carbonates

Carbonates react with acids to produce carbon dioxide. This property of carbonates has been exploited in many ways, both serious and silly.

One of the giddiest applications of this behavior of carbonates is seen in Mad Dawg, a foaming bubble gum developed in the early 1990s. If you chew a piece of this gum, large quantities of foam are produced so that it is difficult to keep the colorful lather from oozing out of your mouth. The froth begins to form as your teeth mix saliva with the gum's ingredients (sodium hydrogen carbonate, citric acid, malic acid, food coloring, and flavoring).

How is this foam produced? When citric acid and malic acid dissolve in saliva, they produce hydrogen ions, which decompose the sodium hydrogen carbonate (baking soda) to produce carbon dioxide, a gas. These bubbles of carbon dioxide produce the foam. Large quantities of foam are produced because citric and malic acids taste sour, which stimulates salivation.

A common medical recipe for a similar combination of ingredients is found in Alka Seltzer tablets; these contain sodium hydrogen carbonate, citric acid, and aspirin. The acid and carbonate react in water to produce carbon dioxide, which gives the familiar fizz of Alka Seltzer.



Alka Seltzer™

Makeup artists add baking soda to cosmetics to produce monster-flesh makeup. When the hero throws acid (which is actually vinegar, a dilute solution of acetic acid) into the monster's face, the acetic acid reacts with sodium hydrogen carbonate to produce the disgustingly familiar scenes of "dissolving flesh" that we see in horror movies. The ability of baking soda to produce carbon dioxide delights children of all ages as it creates monsters in the movies.

Many early fire extinguishers utilized the reaction of sodium hydrogen carbonate with acids. A metal cylinder was filled with a solution of sodium hydrogen carbonate and water; a bottle filled with sulfuric acid was placed above the water layer. Inverting the extinguisher activated it by causing the acid to spill into the carbonate solution. The pressure produced by gaseous carbon dioxide gas pushed the liquid contents out through a small hose.

Kitchen oven fires can usually be extinguished by throwing baking soda onto the flame. When heated, carbonates decompose to produce carbon dioxide, which smothers fires by depriving them of oxygen.

Chefs frequently use the heat-sensitive nature of carbonates to test the freshness of a box of baking soda. Pouring some boiling water over a little fresh baking soda results in active bubbling. Less active bubbling means the baking soda is unlikely to work well in a baking recipe.

Ronald DeLorenzo

Automatic Sunglasses

Sunglasses can be troublesome. It seems they are always getting lost or sat on. One solution to this problem for people who wear glasses is photochromic glass—glass that darkens in response to intense light. Recall that glass is a complex, noncrystalline material that is composed of polymeric silicates (see Chapter 10). Of course, glass transmits visible light—its transparency is its most useful property.

Glass can be made photochromic by adding tiny silver chloride crystals that get trapped in the glass matrix as the glass solidifies. Silver chloride has the unusual property of darkening when struck by light—the property that makes the silver halide salts so useful for photographic films. This darkening occurs because light causes an electron transfer from Cl^- to Ag^+ in the silver chloride crystal, forming a silver atom and a chlorine atom. The silver atoms formed in this way tend to migrate to the surface of the silver chloride crystal, where they aggregate to form a tiny crystal of silver metal, which is opaque to light.

In photography the image defined by the grains of silver is fixed by chemical treatment so that it remains permanent. However, in photochromic glass this process must be reversible—the glass must become fully transparent again when the person goes back indoors. The secret to the reversibility of photochromic glass is the presence of Cu^+ ions. The added Cu^+ ions serve two important functions. First, they reduce the Cl atoms formed in the light-induced reaction. This prevents them from escaping from the crystal:

$$Ag^+ + Cl^- \xrightarrow{h\nu} Ag + Cl$$
$$Cl + Cu^+ \longrightarrow Cu^{2+} + Cl^-$$

Glasses with photosensitive lenses. The right lens has been exposed to light and the left one has not.

Second, when the exposure to intense light ends (the person goes indoors), the Cu^{2+} ions migrate to the surface of the silver chloride crystal, where they accept electrons from silver atoms as the tiny crystal of silver atoms disintegrates:

$$Cu^{2+} + Ag \longrightarrow Cu^+ + Ag^+$$

The Ag^+ ions are re-formed in this way, then return to their places in the silver chloride crystal, making the glass transparent once again.

Typical photochromic glass decreases to about 20% transmittance (transmits 20% of the light that strikes it) in strong sunlight, and then over a period of a few minutes returns to about 80% transmittance indoors (normal glass has 92% transmittance).

NEXT ISSUE:

JULY 2021

SCIENCE & ART IN ACTION!

Science and Art should never be treated as mutually exclusive – there is no better example of this than on our own door step, well at least only 30 miles away: CAMBRIDGE.

The Corpus Christi undergraduate Taylor library occupies a former bank building and in the old doorway of the bank there is a clock...but it's not just any old clock, it's a CHRONOPHAGE.

Also known as the CORPUS clock and the GRASSHOPPER clock, it is a superb amalgamation of Science and Art.

It was designed and funded by JOHN C. TAYLOR, an old member of the college. He has written:

"When I was helping design a clock for the Corpus Christi College undergraduate library, I didn't want to create anything that had ever been done before. The design is an homage to John Harrison who used a grasshopper escapement in the development of his sea clocks. I took the idea of a grasshopper escapement that had been designed by the iconic horologist John Harrison and made it much bigger."

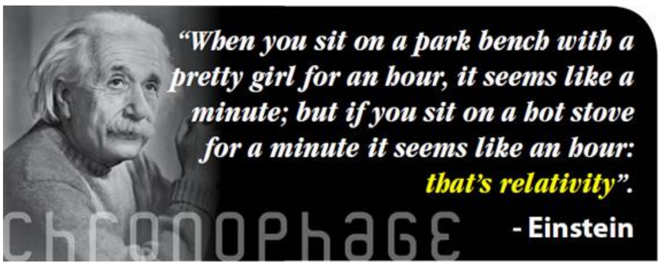
The Corpus Chronophage clock was unveiled in 2008 by the world-renowned theoretical physicist and cosmologist Professor Stephen Hawking and it's been a huge source of fascination ever since.

Professor Taylor adds: *"Adults appreciate the level of artistry, workmanship and humour that have gone into the clock's creation. The ripples on the clock face, which depict time expanding from the centre of the universe after the Big Bang, urge them to contextualise their own existence. I was inspired to create the Chronophage because of modern art. I've never been a fan of it, so I wanted to create something that was modern art but had a bit more to it. I wanted to find a new way of telling time."*

The name 'CHRONOPHAGE' is derived from the Ancient Greek words '*chronos*' and '*phage*', meaning 'time-eater'. The creatures that stalk the top of the clocks will continue to eat time for hundreds of years to come, so the majority of the construction is in stainless steel, gold and enamel, chosen for their longevity.

The scary looking grasshopper on top of the clock is not just decorative, it is an essential part of the clock's mechanism: the escapement. It is the same sort of escapement that John Harrison used (mentioned above).

Although it is an extremely accurate timepiece overall, the Chronophage is designed to regularly speed up and slow down as a demonstration of the relativity of time. When ALBERT EINSTEIN tired of explaining his *Theory of Relativity*, he would tell people:



https://www.johnctaylor.com/the-chronophage/