KES Physics Newsletter

Autumn Term 2020

Figure: The Carina Nebula

Note from the Editor

Hello all! Thanks for taking a look at this terms edition of the KES Physics Newsletter. We've each worked hard to write a little about what we've been working on this last term, and hope you find it interesting! Take a look at the YouTube video recommendations on page 9, and answers to some of your submitted questions on page 10 and 11.

Wishing you all a very happy winter break!

- Rob -

Paul Jarvis

Studied Physics, Chemistry, Maths, Biology

Read BA and MSci Natural Sciences at Cambridge University

Ph.D. in Geology from Bristol University

Currently a post-doctoral research assistant at the University of Geneva

At KES 2001 - 2008

Hello everyone! It's been over four years since Rob asked me to start contributing to this newsletter, so I thought I'ld provide a bit of a general introduction to me and what I do. Currently, I am a research and teaching fellow in the Department of Earth Sciences at the University of Geneva, Switzerland. The majority of my work involves research in the fields of Volcanology and Geophysical Fluid Dynamics. Fluid dynamics is the study of how fluids, e.g., liquids and gases, move in response to the forces acting on them. From a geophysical perspective, the laws of fluid dynamics govern many of the processes that happen on and within the Earth, from weather patterns in the atmosphere to convection in the outer core.

Volcanoes are a particular interest of mine. Volcanic eruptions can significantly impact human lives and livelihoods. As well as presenting obvious deadly hazards, lava flows and volcanic ash can both destroy property and infrastructure. Research is therefore needed to understand how volcanoes erupt, such that the associated hazard and risk can be assessed and mitigated. In collaboration with many colleagues, I try to use physics to understand how various volcanic processes occur.

There are different ways we can study these processes. Firstly, we can use field observations of eruptions and their products (Fig. a). However, the difficult conditions volcanoes create make it hard to get the data we want, e.g., how far and fast does volcanic ash spead? We therefore need to combine these observations with other methods. We frequently perform experiments in the laboratory (Fig. b), where we can simulate the natural processes as well as use mathematical models (Fig. c) of fluid mechanics to describe volcanic behaviour. Consequently, the work is very interdisciplinary.

In the next few articles, I will talk about some of the specifics of my research in more detail. In the meantime, have a Merry Christmas and may 2021 be better than 2020.

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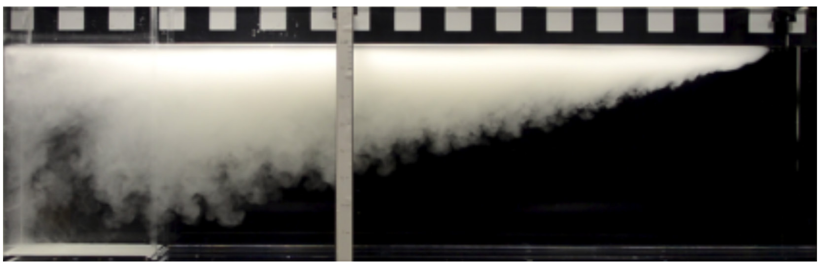
(b)



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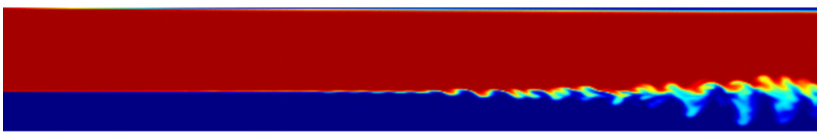


Albert Haladay

Studied Physics, Maths, Computing, Further Maths

Reading Theoretical Physics at Nottingham University

At KES 2013 - 2020

I have just started my first undergraduate year at the University of Nottingham. Here I am currently studying for a master's degree in Theoretical Physics. My favourite module so far has been the Newton to Einstein module. In this module, I have learned about rotational motion and oscillations, which have been very captivating. Rotational motion, for example, has taught me about rotating bodies and the concept of moment of inertia. We have also gone from modelling everything as a single particle to using rigid bodies, which is a strange transition to adapt to and overcome, nevertheless it is enjoyable to progress in my knowledge.

My Quantitative Physics module has also been very interesting, we have learned to use the Taylor series for small difference approximations and potential minima, which is essentially looking and equations and seeing how they change with a small increase. We have also gone further into uncertainties and statistics which I found difficult and would benefit from further use of this topic.

The Mathematics for Physics module has just been solidifying my substratum in Mathematics, so far everything other than partial derivatives has been covered in the Further Maths A level. In a different module, I was taught about an array of different coordinate systems that were not covered in the Maths or the Further Maths A level, such as Spherical co-ordinates and Cylindrical coordinates, which are similar to Cartesian co-ordinates but use more angles which were not very hard to get to grips with; nonetheless, I still enjoyed learning about them.

The Computing for Physical Sciences module has been even-tempered, as it is designed for people that have never done any programming before, however it is enjoyable learning how to use NumPy and Matplotlib to plot graphs in Python since all of my previous programming experience has been in desktop applications in which I have never been required to draw a graph.

The Frontiers in Physics module has been very difficult for me to grasp. Ultrasound and radioactivity were fun, but the MRI section was less so. Interestingly enough Sir Peter Mansfield was a lecturer at my university and won a Nobel prize for his work on MRI, fortunately, I will soon be moving on from Medical Physics and starting the Quantum Mechanics section, which I am eager to explore.

The Experimental Physics module has been difficult, due to the current circumstances, but I have done some very interesting experiments such as calculating the capacitance of a capacitor using the time it took to discharge or the experiment in which I calculated the distance between two points on campus using GPS, however, I found difficulty in calculating uncertainties but I imagine that I will get used to it soon enough.

In conclusion, there have been some rough patches but overall, the start of my course has been incredible, and I feel like I have learned things that I never thought I was capable of.

Callum Shingleton-Smith

Studied Physics, Maths, Chemistry, Computing (AS)

Reading Physics at Royal Holloway University of London

At KES 2012 - 2019

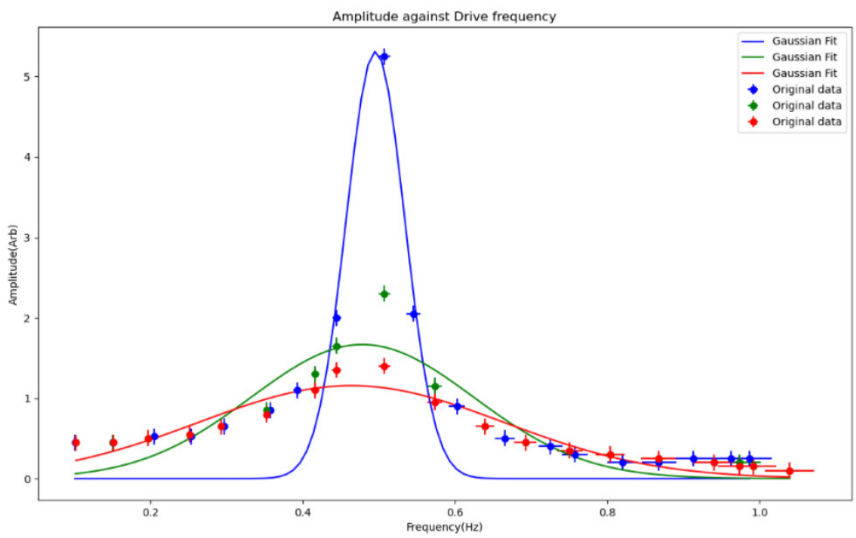
This term has truly been one like no other - university life has altered quite drastically with most of my physics course being moved online, however it has still been a good term where I have learnt a lot.

Year 1 Physics has, so far, been focused on three modules: maths, classical mechanics and classical matter. The classical mechanics module has picked up where A-Level left off however the matter course was completely new and provided a foundation understanding of thermodynamics and energy in systems. The maths module has been relatively straight forward with a lot of the course content being retaught from the previous foundation year – this has helped me keep my focus on the new topics I am learning.

Though in-person teaching hours have been significantly reduced, lab sessions did still go ahead with 6 hours of labs each week for a total of 10 weeks. Here there has been great emphasis on approaching experiments with the scientific method and always being critical of any results collected by carefully analysing the uncertainties at each stage of an experiment and propagating these errors to the final result. The diagram below is a final result for an experiment that investigates the relationship between driving frequency and the amplitude of a torsional pendulum for three trials with different damping factors. Damping of the oscillation increases in the order of Blue, green and then the red line, here you can see that the amplitude of the oscillation is reducing however the peak remains around the natural frequency of the system.

As well as the standard lectures for each module in my course, there have been special lectures which occur every week – these feature physicists from across the university which talk about the field in which they are specialised and they cover a wide range of topics, next term I will have to research and analyse one of these topics and produce a report.

The move to online lectures has been good and bad, though the university experience changed for the weeks of lockdown it was ensured that all of my lectures were recorded and instantly accessible online this proved very handy for revision on specific topics – useful for the end of term tests. This term has still been good overall and I look forward to next year which hopefully shouldn't be as chaotic!



Alex Broad

Studied Physics, Maths, Psychology, Further Maths (AS)

Read BSc Physics at Swansea University

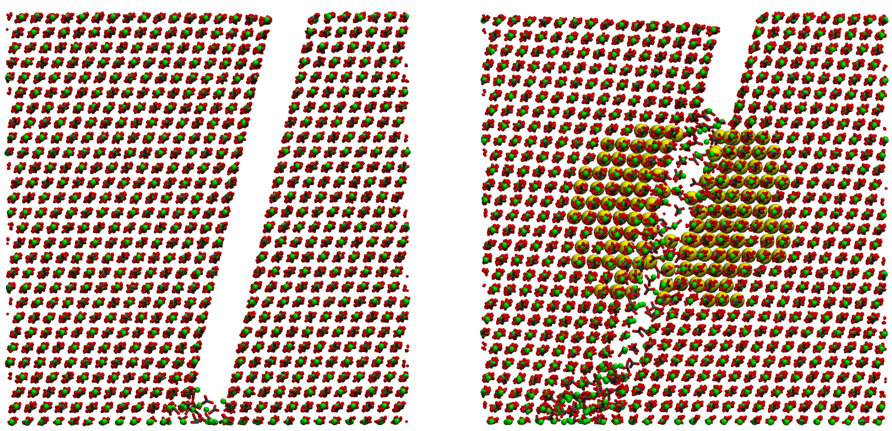
Read MSc Physics at UCL

Physics Ph.D. student at UCL

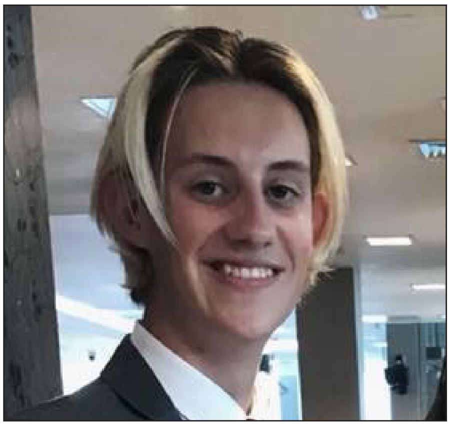
At KES 2012 - 2014

Since I haven't done so for a while now, I think it'd be good to give a recap of what it is I actually do (just in case any of you haven't read every single entry I've written for the last four years). In short: I run atomistic computer simulations of minerals in order to determine how they grow and how to tune their final properties with additives. In other words, I try to use these simulations to understand how animals are able to take minerals that are found in the Earth (stuff like calcium carbonate, which is what I study) and convert them into hard structures, such as bones, teeth etc. Now, I know this might not sound much like physics, and it may not sound so captivating if you're more intrigued by stars/galaxies/cosmology or quarks/leptons/electrons. However, I was in the same boat when I was back at KES and, although what I do sounds a lot more like biology, there is a tonne of physics behind my work. First of all simulations are build entirely on physical processes, such as the motions and interactions between tens of thousands of atoms. Secondly, the methods and techniques I use are entirely based around thermodynamics. So in reality I'm applying physics to biological systems.

Going into more detail: my group and I are trying to understand how additives (often stuff like amino acids, although they can be any impurity really) are able to tune the final properties of calcite, using real examples in biology as a foundation. Some of my recent work involves investigating how magnesium-rich regions in calcite are able to improve the fracture toughness of calcite. For some context: the skeletons of certain types of starfish are partially made of calcite. While this is mostly ideal for them, the natural brittleness of calcite does not make it a great choice for a skeleton. However, by using these magnesium-rich regions, these starfish have found a way of making their bones less brittle. Experimentalists were only able to offer some guesses as to why magnesium is able to do this. However, my simulations were able to offer a much better picture. The picture I've attached shows different cases of a crack propagating through calcite either without (a) or with (b) magnesium. You can see that, not only does the magnesium (shown in yellow) cause a much less clean break, but the crack is actually sometimes deflected away from its preferred direction. All of this amounts to a structure much harder to break. To give some perspective, each dot in the picture is an atom, and each magnesium (yellow) region is about 4 nanometres wide.



(a) (b)



Fin Cooney

Studied Physics, Maths, History, Further Maths (AS)

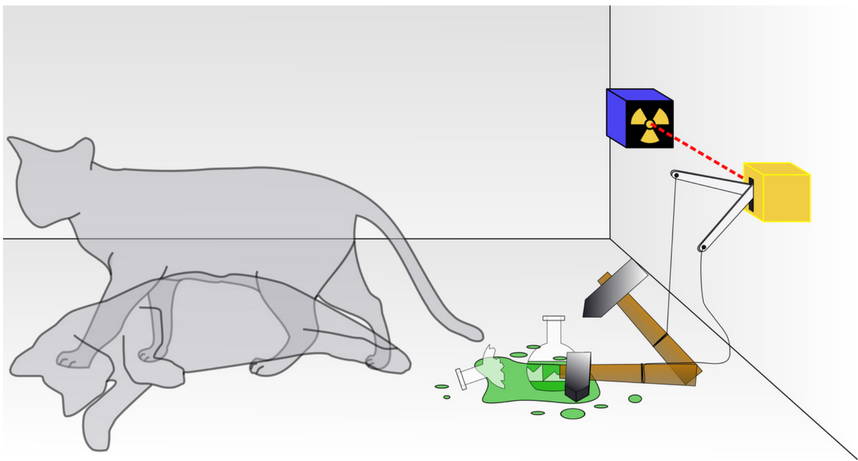
Reading Physics at Loughborough University

At KES 2011 - 2018

This semester my main physics module has been quantum mechanics; the study of the physical properties of nature at the atomic and subatomic level. We started off learning some new notation, invented by Paul Dirac, aptly known as Dirac notation. This notation helps us simplify operations involving matrices and vectors. In quantum we use a lot of matrices and vectors and are also introduced to a new sort of matrix called an operator. When we apply these operators in certain ways, we can determine things called observables which are basically physical properties of the particle, for example the particles position. The reason we can't just use classical mechanics to solve quantum mechanics is that if we know a particles position, it means we have taken a measurement of its position relative to something. Say if you take an electrons position in a lab, you're taking its position in the labs reference frame (relative to the lab). However, the problem that quantum theorists were faced with, around 100 years ago, was this; when it comes to atomic and subatomic particles, before you take a measurement of them their position is not exact. It is actually a probability function. This means that before you measure a particle's position it is sort of everywhere it could possibly be at that moment in time, not in a single position. When studying quantum, we use some maths and intuition to find out the values of different observables by using these operators and other things, this is the main gist.

You're probably wondering, "what's the point of all of this?", "what's the use in knowing where incomprehensibly small particles are?". There are myriad applications of quantum computing. If you're reading this electronically then quantum mechanics has been used in the device you're holding. We are also seeing quantum computing flourish.

Part of my coursework this year has been to assess a paper published this year on a new breakthrough in quantum computing. The paper is actually very interesting as it is at the forefront of the field. The paper, in essence, is showing how a new filter is put into the system meaning that it can run for longer and do more computation, quicker. The breakthrough is a leap forward in quantum computing and will no doubt have large repercussions.



Zak Goble

Studied Physics, Maths, Economics, Further Maths (AS)

Reading Physics at Manchester University

At KES 2010 - 2017

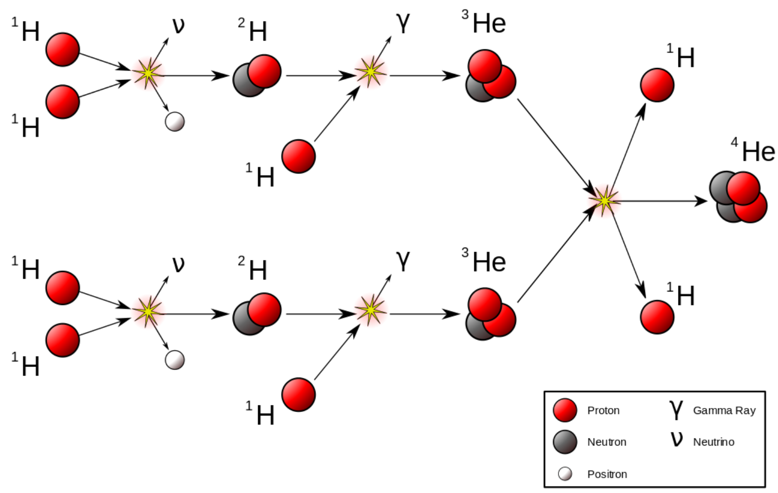
I'm Zak, and if you don't think my article is the best, then this newsletter is fraudulent and rigged. In my 7th of 8 terms at Manchester, I'm studying gravitation, frontiers of particle physics, radio astronomy, and nuclear fusion with astrophysical plasmas.

Gravitation is the module where you finally learn about general relativity (black holes and all that. Basically everything that happens in Interstellar but without the weird Tesseract thing at the end). Time speeds up when you approach a black hole. Light itself bends round the edges. When you reach a certain distance from the centre of a black hole – a distance known as the Schwarzschild radius – not even light can escape. That's game over for anyone and everyone.

Frontiers of particle physics looks at the biggest and best particle colliders (always the LHC at 27km in size) and the coolest new particles. Particle physics is essentially a manly contest of 'who can find the biggest particle', and the discovers of the top quark, nearly 200 times heavier than a proton, are currently in the lead. The current aims of the field are to explain dark matter and dark energy (which, at the moment, nobody has a clue about either), and to work out how gravity works for small-scale bodies like particles.

Radio astronomy works with telescopes to detect distant astronomical sources, like supernova explosions. This naturally leads to another battle of 'who's got the biggest', and this time it's in the case of telescopes. The largest single dish scope in the world is the China Sky Eye, sitting pretty at 500m across, but not all telescopes have just one dish. Interferometry is a relatively new 'cheat' field of physics that connects lots of small antenna dishes all over the world and pretends it's just one giant dish with lots of holes in. The biggest antenna dish in the world, using this method, is currently the size of the whole world.

Nuclear fusion is arguably the most promising area of physics at the moment simply with the fact that it could slash the cost of energy and electricity by a factor of a thousand. It outcompetes every other form of energy in the world in terms of cost, sustainability, abundance of required fuel, the fact that it doesn't produce any by-products such as toxic waste or carbon dioxide – it wins everything. The only drawback is that achieving fusion is currently impossible. You need a whole lot of pressure and temperature to reach fusion, like in the centre of the Sun, that we're just not able to replicate on Earth yet. Reaching fusion would easily be the biggest breakthrough in physics.



Robert Clemenson

Studied Physics, Chemistry, Maths, Further Maths

Read BA Physics and MMathPhys Mathematical and Theoretical Physics at Oxford University

Physics Ph.D. student at Sussex University

At KES 2008 - 2015

It's been a funny old term. Moving to a new town & University mid-pandemic presents a whole host of challenges! Fortunately, my group at Sussex University (the Theoretical Particle Physics group) has been very supportive, and is providing a stimulating and welcoming (albeit virtual) research environment.

Taking heavy inspiration from Paul and Alex's article themes, I thought it would be a good idea to re-introduce myself to you all, and talk a little about the kind of physics I do!

Firstly, what exactly does a PhD student do? Well, doing a PhD is quite different to doing an undergraduate degree. There's a lot less attending lectures, and doing assignments. The idea is to make new contributions to science, and work on problems people haven't yet solved. That being said, as I'm just starting out, I'm mostly just reading papers and trying to reproduce results others have already figured out!

My research interest is broadly located within the intersection of particle physics and cosmology.

The very early Universe was a very hot and very dense place. As the Universe expanded and cooled, it underwent a kind of phase transition. You can think of this in much the same was as how liquid water changes *phase* to solid ice when cooled below 0 °C. However, this phase transition in the early Universe was not a change from one state of matter to another; it was a transition from one particle physics epoch, to another.

The specific phase transition I'm referring to, is the 'electroweak phase transition'.

We know that in our Universe, there are four fundamental forces of nature: The ***Electromagnetic Force*** (responsible for holding atoms together, and keeping fridge magnets in place), the ***Gravitational Force*** (which holds galaxies and solar systems together), the ***Weak Nuclear Force*** (which allows radioactive decay to take place), and the ***Strong Nuclear Force*** (which holds the nucleus of an atom together).

In the 1960's it was discovered that the electromagnetic force, and weak nuclear force morph into a single force at high temperatures (around 10^{15} Kelvin). This is roughly how hot the Universe was 10^{-11} seconds after the big bang.

Our picture of the electroweak phase transition, as it really happened in the early Universe, looks rather like the way that a bottle of supercooled water freezes when hit (See this video by Veritasium).

Even below this 'critical temperature' of 10^{15} Kelvin, the electric and weak forces don't suddenly pop apart. They need something to get the transition started. Just like supercooled water needs a whack (or some impurities) to get it to freeze.

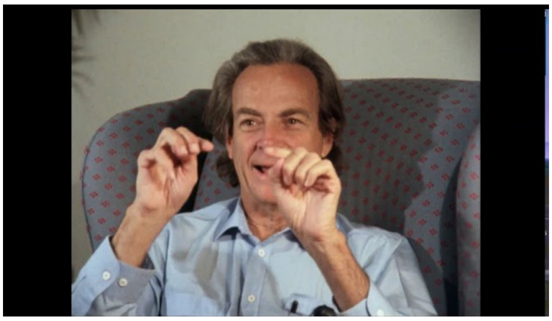
These cosmologial phase transitions are very interesting, and could teach us alot about fundamental physics. With a space based gravitational wave telescope (LISA) due to be launched in 2034, we stand to figure out a lot more about the early Universe in the next few years.

Youtube Video Recommendations

Click the video thumbnails for links to the videos

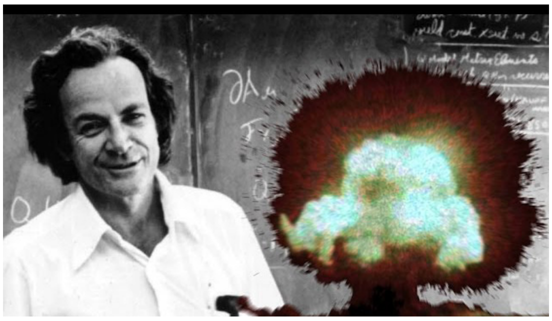
A Brief Introduction to General Relativity with Anthony Zee (The Royal Institution)

In this hour long talk, Professor Anthony Zee gives a thorough history and very clear motivation for Einsteins theory of gravity (general relativity). This would be an interesting talk for year 13 students curious about gravity, and what Newton's formula doesn't tell us.



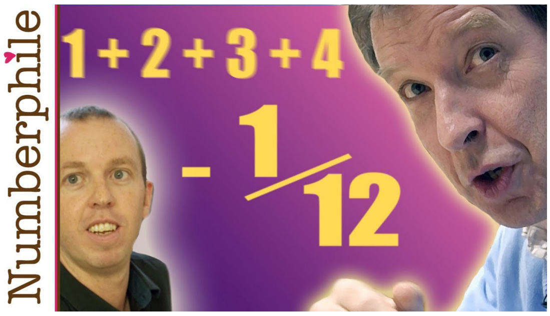
Fun to Imagine - Richard Feynman

I've listened to this interview with Richard Feynman more times than I'd care to admit. His curiosity, and pure joy in imagining the ways the Universe works is contageous. Feynman is one of my physics heros, and this interview gives a good idea of why!



Los Alamos From Below - Richard Feynman

Another talk by Richard Feynman. This highly entertaining lecture given in the 1970's details an inside view of the Los Alamos National Laboratory during the US atomic bomb project. Expect Feynman's characteristic humour, including safe-cracking anecdotes!



ASTOUNDING: 1+2+3+4+5+...= -1/12 (Numberphile)

A classic numberphile video, and a classic result for prompting confusion and debate in A level maths classrooms up and down the country.

A Baffling Balloon Behaviour - Smarter Every Day 113 (SmarterEveryDay)

This is a fun experiment you can do yourselves (if you have access to a helium balloon, and a reasonably large car - though I suppose you could recreate this on a bus/train, if you don't mind the funny looks). The explaination in this video is also rather nice!

Questions and Answers

Submit your questions to Miss Heggie, or through the Cosmic Conundra contact page

Your questions this term were all fantastic! I've only shown a small number here, but you can find answers to the others on CosmicConundra.com under 'Problems', and 'Questions & Answers'.

What is a Wormhole? Are they real? (Year 7)

A wormhole (or an 'Einstein-Rosen bridge' to use the historic name) is a hypothetical 'tunnel' connecting two potentially quite distant regions of space. I use the word 'hypothetical', not because these things are total guesses. They are in fact a prediction of Einstein's theory of gravity (which, although not perfect, usually gives us a reasonably good idea of what's going on).

Whether they are *real* or not is a different matter... Certainly we have never knowingly directly seen one. If they are *real* in some way however, it isn't thought they they would be useful as a faster than light shortcut between distant parts of the Universe. They may not even be traversibe at all!

Robert Clemenson

Is the Moon really made of cheese? (Year 12)

When man went to the Moon in 1969 he brought back samples. These samples contained, among other things, silicon, aluminium, iron and oxygen. However a more recent expedition in 1989, in which they were able to taste a sample, resulted in the following quote:

"It's like no cheese I've ever tasted" - Wallace

From this we can conclude that the Moon is made of something edible that works well with crackers. But is it made of cheese? I'd say more research is still required.

Tim South (MEng Aerospace Engineering, Bristol University 2019)

If the wavefunction of a Bose-Einstein condensate goes outside of it's container, would the entire condensate tunnel, or just a few particles in the container? (Year 12)

Wow, what a technical question! You've clearly been reading beyond your A level syllabus!

Let's first describe what a Bose-Einstein Condensate (or BEC as I will call it) is. A BEC as a system of bosons (particles with spin taking a whole number value) that has been cooled to such a low temperature, that the majority of particles have settled into the same lowest energy state. This has some extraordinary consequences for how the system will behave.

Particularly, the system exibits 'quantum like behaviour' on a macroscopic scale. This is bizzare, as quantum effects are usually reserved for very small objects (roughly on the scale of a nanometer).

One such behaviour is the ability to tunnel quantum mechanically, which brings me to your specefic question.

In quantum mechanics, the *wavefunction* of a single particle can roughly be thought of as a function that describes the probability of where you might find that particle. When you have a system of many particles (as is the case for a BEC), things do become a little more complicated. Your wavefunction no longer contains information about just one particle, but about a number of different particles. We can think about the BEC wavefunction as describing the probability of an individual particle within the BEC being found at a given location. If the wavefunction extends beyond the bounds of the containter (or more pragmatically, beyond the bounds of the trapping potential containing the BEC), then there is a non zero probability that some particles will make it out.

This leads to particles escaping the container via tunnelling, but not all at once. The number of particles still in the container will decrease as an exponential, in a very similar way to expotential decay from your A level syllabus.

Robert Clemenson

Is it possible for scientists to go to Mars and do experiments? How long would it take to get there, and could they come home again after?
(Year 7)

Elon Musk's company SpaceX is currently our best shot at getting to Mars. The company plans to launch an uncrewed mission in 2024 to Mars, demonstrating that their 'Starship' can make it there.

Musk says he currently doesn't have any plans to start a Martian base but the fact that a ship will be going there in 2024, demonstrating that its possible, definitely makes it more likely. It is more likely that musk will provide the transport there and a government will set up the colony.

As far as experiments go, the first team to go to Mars will probably do some of the groundwork in making sure that humans can live on Mars. We currently have no idea what the effect of living in low gravity on the human body is – we only know the effects of Earth gravity and no gravity (ISS sort of). We also will probably need to monitor lots of other factors such as the radiation there and whether or not growing food is a viable option. These are all important preliminary factors that we will need to take into account.

Every 1.6 years, Mars is close enough for us to launch a mission and it takes around 260 days to get there. To bring up Elon Musk again, his plans are to have a fully reusable rocket that will be capable of flying to Mars and back, though how this is done is still up for debate. To get home there are a few different approaches that have been mentioned. One is to send things like mining and processing equipment there far in advance of the humans going, using this equipment to refine a rockets worth of fuel and use that fuel for when humans eventually need to get back. Another option would be to send two or three rocket to Mars, one containing the astronauts and the other rockets to carry fuel for the return journey.

Fin Cooney

What good jobs could you get out of physics?
(Year 12)

In my very biased opinion, the best job you can get after studying physics is to be a volcanologist. In this job, I've been lucky enough to travel to volcanoes around the world! But in all seriousness, individuals with physics degrees are very attractive to employers in a variety of sectors. This is because through studying physics you develop quantitative analytical skills which can be applied to problem solving. Lots of physics graduates therefore go on to work in business, finance or engineering consultancy. Additionally, physics degrees involve a fair bit of computer programming, so technology and software development firms are also interested in hiring physics graduates. Finally, like me, many physics graduates also go into research, either within physics or applied fields (e.g., biology, geology, architecture).

Paul Jarvis

What will happen to humanity when the Sun explodes?
(Year 7)

As of the time I'm writing this, we have around another *checks watch* 8 billion years left until our sun reaches it's maximum size in the red giant phase of it's life. When the sun gets to this bloated state, it will certainly have engulfed Mercury, Venus and Mars, and in all likelihood the Earth too.

But this is a long way off. The good news is, hopefully by this time humanity will have spread further afield beyond the boundaries of our own solar system. The bad news is, if we have not, we will have been quite lucky to make it another thousand years, let alone another 8 billion. With the impending threat of man made climate change, the possibility of supervolcanic eruptions, and civilisation threatening meteorite strikes, 8 billion years seems a little overly optimistic!

Robert Clemenson