KES Physics Newsletter

Autumn term 2019

Harry Baskett

Studied Physics, Maths, Further maths, French

Reading Physics and Astrophysics at Exeter University

At KES 2012 - 2019

I started my first term in September and drove the 6 hours to Exeter to move into my flat. I thought this first entry to the newsletter would be a good opportunity to introduce the physics I have studied so far and the modules I will be talking about in later newsletters. Overall, I have enjoyed the first term a lot and hope to enjoy the rest of my time at university equally.

So far, the high point has been the five modules I have taken. We have covered an astrophysics module which began with quantum theory and ended with studying the lifecycle of stars. It's interesting to see how the phenomenon on the quantum scale affect processes at large scales. At the same time, we covered vector mechanics which teaches Newtonian and Einsteinian mechanics using vector notation. So far, the maths module has been about bringing everybody up to the same level of maths skills by reteaching the A level content.

In our practical sessions we take data experimentally and find the errors in our measurements, this is very different from A level experiments which rarely work as intended (as I'm sure you well know) and have no error analysis. These experiments are varied, I have watched people "play" with liquid nitrogen whilst I drop a ping pong ball 100 times!

My final module, IT skills, has been spent learning how to produce graphs using python and write lab reports in LATEX, this goes hand in hand with my practical module in preparation to write scientific reports for my experiments next term. Speaking of which, in January I have final exams for my first term physics and maths modules and then begin a new set. Including a second maths module and covering electromagnetics, optics and properties of matter in physics.

My first term of university has taught me a lot about independent learning and organisation - finding a balance between coursework and a part time job means that time management has become a key part of my daily routine. The pace of teaching has definitely increased from sixth form, so starting assignments early and reading ahead is essential.

Callum Shingleton-Smith

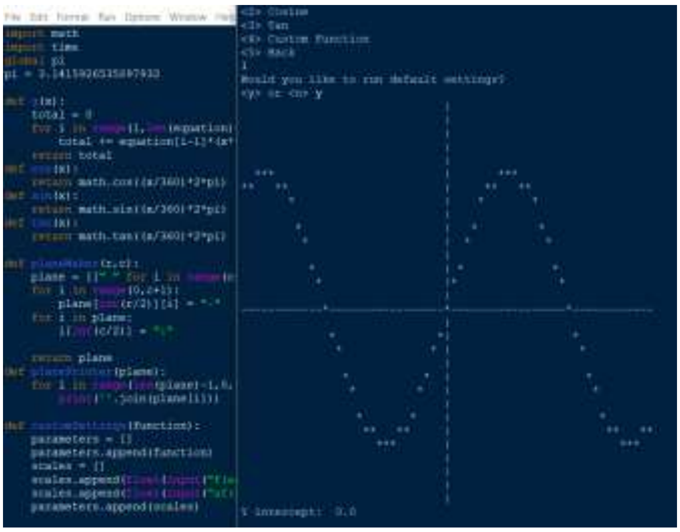
Studied Physics, Maths, Chemistry, Computing (AS)

Reading Physics (with a foundation year) at Royal Holloway University of London

At KES 2012 - 2019

Currently, in my foundation year programme, the two modules that I am most focused on are Maths and Computing, these will be very important for physics next year so I'm making sure I have a full understanding of both modules. A major part of the course is building on the content from A-Level, for example the maths I am doing now overlaps with a lot of the A-level further maths content. It has been especially interesting learning about the proofs for many of the formulae we use on a day to day basis and how we can apply these to many areas of Physics and Maths. Lately we have worked on deriving Euler's identity ($e^{i\pi}+1 = 0$) which was quite interesting.

The computing module involves programming in python, this will be useful for next year since we will have to write custom algorithms to analyse and graph results from experiments. With python being a relatively simple open source language there is a lot of freedom when it comes to writing specialised programs. A python project I have been working on recently is a graphing program like Desmos which can graph custom functions and tell you their properties.



Overall my first term at university has been great, and I'm looking forward to continuing my course in the next two terms. Some advice I would give for new students would be to make the most out of your time and the resources available to you – at RHUL for example they have a library open all hours where you can catch up on work and study.

Zak Goble

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

Reading Physics at Manchester University

At KES 2010 - 2017

I'm Zak, and I'm the only person from KES ever to get an A* in A level science. If you've only got time to read one article and are looking for the most advanced physicist's, look no further. This term, I'm studying Electromagnetic Radiation, Applications of Quantum Mechanics, Introduction to Nuclear and Particle Physics, Non-Linear Physics, and Condensed Matter.

Introduction to Nuclear and Particle Physics is basically just A level physics. We've learnt about the standard model of particles and fundamental forces, and why physicists just *can't* work out how gravity works at that level. We've also studied the semi-empirical mass formula, which describes mathematically why the masses of atoms is not equal to the total mass of the individual particle constituents. We've also covered Feynman diagrams, just like at A level, but with the exception that we have to do them properly now.

Non-Linear Physics is a very mathematical course. We study bifurcations, Jacobians, a whole range of other weird words, and attempt to analyse equations of motion through differential equations (typically in the form $\frac{dx}{dt} = f(x)$ for the nerds that know what that means). In one of our lectures, I'd very unfortunately forgotten to put my phone on silent and, of *course*, that was one of the very rare occasions on which I get a phone call. Even more unfortunately, I'd changed my ringtone to 'Zhong' by Chocolate Puma, which immediately kicks off with a bouncy electro drop, and then set it to play at full-blast the day before. Since then, I've been officially labelled a disturber of the peace.

Electromagnetic Radiation is one of my favourite courses so far. In that, we've learnt that particles have to be accelerated in order to emit radiation, and that the radiated energy is practically negligible relative to the particle's total energy. It also builds on what you learn about cyclotrons at A level, and throws back to the ever-important Faraday's law. It turns out that both the electric and magnetic fields can be proven to be waves in a free space, which is simply enlightening.

Applications of Quantum Mechanics is a *cool* course taught by an even cooler lecturer. He's the kind of guy to wear a smart suit and tie, but then the *freshest* pair of Nikes money can buy. The main focus of the course is quantum tunnelling, where a particle can wriggle its way through a barrier that otherwise wouldn't have been allowed in classical physics, leading to the infamous quote, "you need a mechanic? Get a quantum mechanic! They'll get your car out of the garage without even opening the door." Saying that, they're more likely to get it through two doors than they are one.

I have no idea what Condensed Matter is. You know those things that teachers say where you think, "this is such an obscure point, I won't bother writing it down"? In Condensed Matter, I feel like that with *everything* our lecturer says. My notes for that are completely empty, as is my knowledge of the subject.

We only do two big experiments in the lab this year, nine until five on Tuesdays and Thursdays, and my first has been on matter-antimatter asymmetries at the Large Hadron Collider, which is all about detecting whether or not there's a difference between how matter and antimatter behave in interactions. We were given a data sample from the LHCb experiment of around eight *million* decays of particles known as B mesons and a whole month to analyse them. It turns out that there is a small difference – about four percent using our analysis – but not enough to explain why everything around us on Earth is matter rather than antimatter. Nobody knows why that is yet. The coolest thing about matter and antimatter comes in the form of the question, "what would happen if you met your antimatter self?" that we were asked at A level. It turns out that you'd annihilate yourself and release enough energy to destroy a good amount of the Earth. You could *literally* high-five yourself and blow up the world.

The crucial part of only doing two big experiments in the year is that they're only during the first and last six weeks of the year. Because all our lectures are podcast and permanently placed online, for the rest of the year – I can work from home! I don't have to be there at all! Imagine how doomed KES would be if that was the case there. In terms of the university, though, it suits me perfectly.

Zak

Fin Cooney

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

Reading Physics at Loughborough University

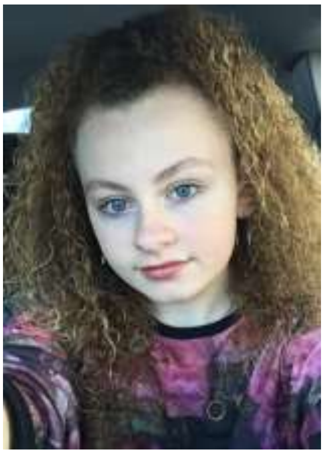
At KES 2011 - 2018

For those who are new to the letter or have not read my column before, my name is Fin and I'm now a first year Physics student at Loughborough University. Having done a Foundation year here at Loughborough – I would recommend the course. It is effectively an extra year consolidating A level topics to make sure you're ready to start the actual degree.

This year is very exciting for the Physics department at Loughborough as the section has undergone, for no want of a better word, a *reformatio.* A word, outlined in R.W Scribner's book 'The German Reformation', that meant, "the restructuring of a university study curriculum (the sense Luther most commonly used it in)". The word has other meanings too; to do with new legal codes and also theological restructuring. The latter definition was less so used by Luther ironically, but I think it is now time I stop myself from digressing too far.

Everything on the new course is effectively intertwined, meaning that on Monday we'll have a new topic in the Maths lecture first thing; this idea will then be built upon in the subsequent Maths lectures. The Maths we learn is then mostly applicable to what we will be doing in Physics that week. We then have a Computational module where we program the Mathematical formulae which can help us solve the Physics problems. The final element to this semester is a module entitled, "Methods, Philosophy and Frontiers of Physics". It's actually very refreshing as a module. The three other modules are all effectively the same thing, so to have something completely different and stimulatingly subjective is nice on the mind.

For example, this week we covered basic Lagrangian Mechanics in Mathematics, modelling systems with it in Physics and then programming these systems in our Computational module using Swift 5. This method learning is really enjoyable, and it makes you see why we're learning these things and what the applications of this knowledge are. The Philosophy module isn't really as connected to the others, but it does still show us where our knowledge comes from and also shows us why it is important to practice science ethically and responsibly. It also shows us the history and thought process behind what we are learning.



Hello again everyone! So, I'm now in the second year of my Mechanical Engineering degree and I've almost finished my first semester. Honestly, I cannot believe how quickly the time has gone. A new semester means a new set of modules and my current ones are; Thermofluid Mechanics, Computer Aided Engineering, Dynamics, and Further Engineering Mathematics.

Trinity Wills

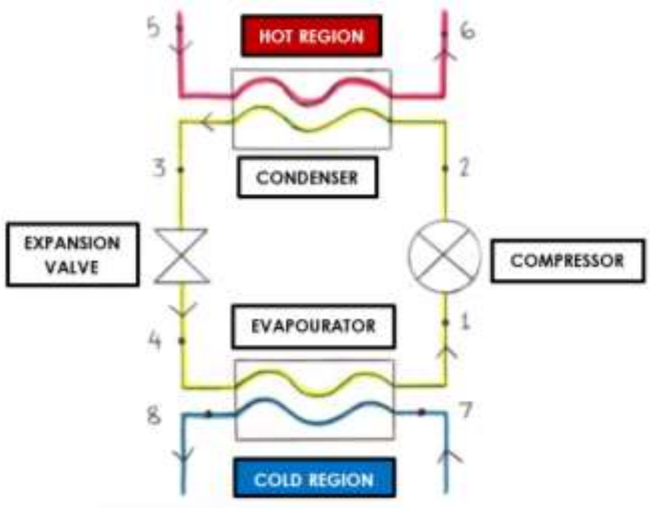
Studied Physics, Maths, Art

Reading Mechanical Engineering at Hertfordshire University

At KES 2011 - 2018

Within my Thermofluid module we have been learning about heat pumps which I think are are pretty cool piece of equipment. Within nature heat innatley flows from a hotter area to a cooler area. A heat pump reverses this process by enabling it to be possible to transfer heat from a cold region to a hot region. This means even if it is cold outside a heat pump can extract energy from the cold air and tranfer it to heat the rooms indoors. It does this by the use of a refrigerant. In the diagram water (Red and Blue) and refrigerant (Yellow) are used. Cold water and refrigerant are passed through the evapourator. Due to the fact the refrigerant has a much lower boiling point than water for example it causes the refrigerant to evapourate. The refrigerant is then compressed to raise the temperature. At the condenser the now high temperature regrigerant transfers heat to the water in the hot region. The refrigerant then passes to the expansion valve where the pressure is lowered and the process repeats.

Heat pumps are also very efficent because the only input energy they require is at the compresssor and for every unit of electricty they use 3-4 units of heat is provided. Heat pumps are now being fitted into new build properties and retrofitted into older homes. I think they are a very useful tool and I look forward to learning about more concepts in my new and upcoming modules.



Thank you for taking the time to read,

Trinity xx

Robert Clemenson

Studied Physics, Chemistry, Maths, Further maths,

Read BA Physics at Oxford University

Reading MMathPhys Mathematical and Theoretical Physics at Oxford University

At KES 2008 - 2015

As you may have noticed from the box on the left, I finished my degree! Now I'm staying on for another year at Oxford, to do a masters degree in Theoretical Physics. My main focuses this year are: Quantum Field Theory, String Theory, General Relativity, and Cosmology. All rather exciting!

This term has been the busiest to date. My lecture courses have been: Quantum Field Theory, Groups and Representations, and the first of two General Relativity courses.

The most challenging (but in many ways, the coolest) of these was undoubtedly the Groups and Representations course. These lectures were tricky mix of abstract mathematics, and particle physics. We spent some time studying the so called 'Georgi-Glashow' model, which was a grand unified theory proposed in the 1970's. It's really cool to see new predicted particles pop out of the mathematical formalism! (Even though none of these particles have been found…)

Courses aside, this year I will also be writing my dissertation. The title I have come up with is 'Models of Cosmic Inflation, Past and Present'. Inflation is the idea that around 10^{-34} second after the big bang, the Universe is believed to have grown exponentially quickly. There are several models of how this process actually works, some based on string theory, some involving the Higgs boson, and others! In the dissertation I will comparing properties of these models and discussing those which have not yet been ruled out by measurements of the Cosmic Microwave Background.

As I mentioned in the last newsletter, I spent this summer working in the mathematics department at Caltech (Yes… I spent a summer as a theoretical physicist at Caltech… No… I don't watch the big bang theory!). I'm happy to say, some of the work I did went towards a publication, which I am acknowledged in. While at Caltech, I went to a lecture by Dr Katie Bouman (remember the viral picture of a researcher alongside the first 'photo' of a blackhole? Her!) discussing her work, which was really interesting!

In October, I attended a workshop in Argentina on how volcanic ash can continue to be a hazard to humans long after an eruption. In June 2011, a volcano called Cordón Caulle, Chile, erupted explosively, producing approximately 100 million tons of ash. As you can see in the photo (Source: Nasa Earth Observatory), the ash cloud spread across the width of Argentina. Volcanic ash can have large negative impacts for humans and animals. Fine particles (< 10 μm) are easily breathed in and can cause respiratory problems. Furthermore, deposited ash can cause roofs to collapse. In Patagonia, where much of the ash fell, one of the primary industries is farming, but ash deposited during the eruption destroyed crops and contaminated animal feed. Therefore, it is really important to understand how ash is dispersed and deposited during a volcanic eruption, so that appropriate risk management can take place.

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

The 2011 eruption also highlighted that the hazard due to ash can endure for years after the eruption. Parts of Patagonia are very flat with high surface winds. This means that deposited ash can be re-suspended into the atmosphere, even creating ash storms in high winds. Thus, volcanic ash continues to damage human health and slows agricultural recovery.

During our workshop, we discussed the science of volcanic ash resuspension. Much research focuses on determining how strong the wind needs to be to lift ash into the atmosphere, and the development of models that can be used to forecast ash storms. We also met local people who were affected by the eruption and subsequent ash storms. As a scientist, it was an eye-opening experience to interact with people who have suffered due to volcanic activity, and it really highlighted the need to have good collaboration between physical and social sciences.

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

Being over a year into my PhD, I'm starting to gain some understanding not only of what it is I actually do, but what life as a researcher is like in general. I can offer a slightly controversial opinion here, that studying for a PhD is actually far less stressful than studying for a degree - or even A-levels. The hard work is still there of course, but as a researcher, you enjoy what you do. Getting stuck into a problem and writing about my work is certainly more enjoyable than practising exam technique. The initial aim of my PhD, which was to model crystal growth in the presence of additives in order to further understand biomineralisation, has somehow branched out into a weird network of side projects and collaborations.

I've recently had the good news that some of my work is going to be published, which I'm very happy about. My contribution to the paper wasn't major, but still fairly significant: it mostly involved cutting different geometries of holes in a calcite crystal and measuring the average change in atomic spacing for different concentrations in order to explain some unusual results found by experimentalists. I won't go into the details, but this was all done by computer simulations because the experimentalists didn't know what the hole geometry actually was. I was able to help them by finding the geometry that agreed the most with their data.

I am also in the final stages of preparing another paper, of which I am the main author. A while ago some people found that part of the skeletons of a certain type of starfish were made of calcite: only, when they looked closer, they found regions with high concentrations of magnesium. Given that calcite doesn't naturally grow this way, they set about trying to explain why a starfish would want to put magnesium in their skeletons in this way. Someone proposed that these magnesium-rich regions exist to prevent cracks propagating through the crystal. They do this by compressing the crystal locally, which prevents cracks from pushing through. It's only natural that starfish, like people, don't want their bones to break. More recently still, I was able to provide theoretical justification that what they proposed is correct. I also was able to demonstrate new effects which may contribute to the improved toughness of this unusual crystal. Hopefully I'll have a paper out of that too, but we'll see!

Physicist Profile: Emmy Noether

Born in the city of Erlangen Germany on March 23rd 1882, Amalie Emmy Noether (pronounced *Nerter*) remains one of modern-day theoretical physics' most influential contributors.

At the time of her birth the doors to University education had only just begun to creak open for women in Europe and America. Despite being one of the most talented mathematicians of the last two centuries, she faced discrimination from some of her contemporaries (initially being unpaid for her work and teaching!).

In 1915 she was invited to conduct research at the University of Göttingen by David Hilbert and Felix Klein (two other influential mathematicians/physicists of the 19th/20th century). At this time women were not permitted to give lectures, so classes would be listed as being given by David Hilbert who would sit at the back while Noether gave the lecture.

One of her many contributions to physics is a theorem that shares her name, 'Noethers Theorem'. This result relates symmetries of nature, to conserved quantities. Motivated by this in no small part, much of modern theoretical physics is dependant on an understanding of 'fundamental symmetries', as opposed to 'fundamental conservation laws'. (Note: By fundamental, I mean the end of a line of 'why?' questions. If something is 'fundamental' it cannot be explained by some more basic logic or principle.)

For example, we might think of 'conservation of energy' as being a fundamental principle of nature. But in fact, conservation of energy can be thought of entirely as the result of 'symmetry under time translation'.

This change in language, whereby physicists now think not of statements of conservation (like conservation of momentum, or conservation of energy) but instead of the symmetries of physical systems has revolutionised the way in which we understand physics.

There's a nice YouTube video by the Royal Institution: 'What is Symmetry in Physics? With Tara Shears', if you would like to hear more!

Problem Page

1) **[All years] Measuring the Moon.** For this problem you will need, a 5p coin, a long ruler (or straight stick you can mark and measure after), and a clear night!

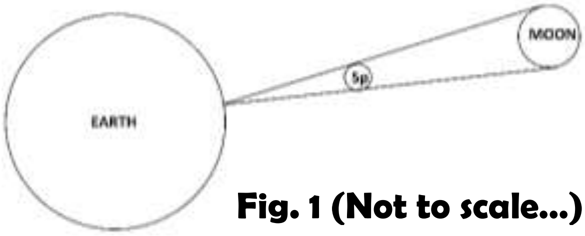


Fig. 1 (Not to scale...)

We are going to use the properties of similar triangles, a few rudimentary length measurements, and the average distance of the moon from the Earth (something we *can* measure, but not at home!)

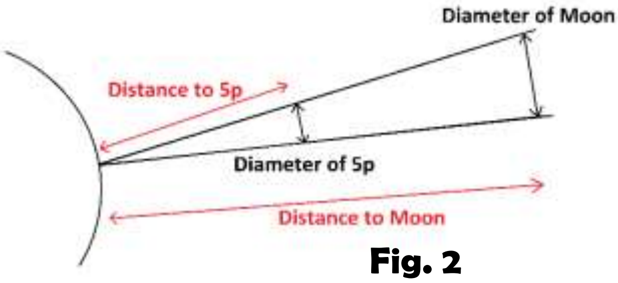


Fig. 2

Measurement: Step outside on a clear night when the moon is visible (and preferably full). Close one eye and hold a 5p coin out in front of you between yourself and the moon. Hold your arm at a distance such that the coin only *just* blocks out the moon. Measure this distance between your eye and the coin. You will also meet to measure the diameter of the coin you used.

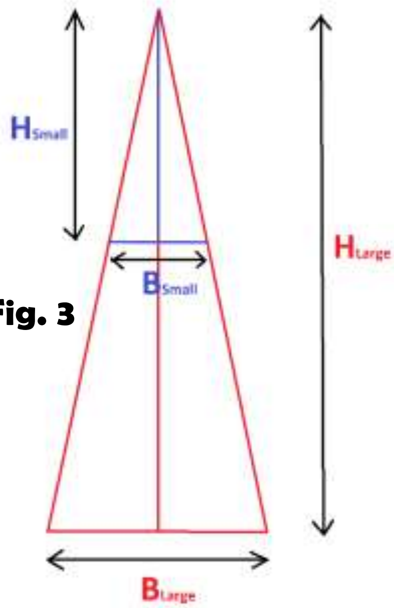


Fig. 3

Calculation: By the geometric properties of the similar triangles in Fig. 3, we can relate:

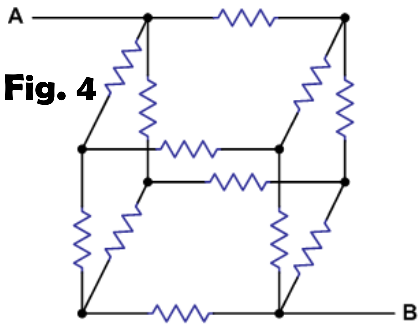
$$\frac{B_{Small}}{H_{Small}} = \frac{B_{Large}}{H_{Large}}$$

The last ingredient you will need, is the average distance between the Earth and the Moon. Which is, 384400 km.

You now have everything you need to make an estimate of the Moons diameter! You might improve the accuracy of your results by averaging the number you get between multiple members of your class.

2) **[Year 12 +]** If a battery is connected between terminal A and terminal B of the 3D circuit shown in Fig. 4, what will be the total resistance felt by the battery? (You may assume every resistor has constant resistance, R).

Fig. 4



Questions and Answers

How expensive is going to space? (Billy – Year 9)

Very! … Okay, okay, I'll give a bit more detail. The cost of going to space varies depending on how far out you want to go and who you're flying with. The total cost of a trip on the space shuttle was around $1 Billion, though it was an exceptional spacecraft in both design and capabilities. The Russians currently charge NASA and ESA $75 Million for a seat on the Soyuz however the cost should become much lower when Space X and Blue Origin bring some competition to the market. If you want to learn more about space tourism, look up Dennis Tito, the first person to pay for their own trip to space. – *Tim South (MEng Aerospace Engineering, Bristol University 2019)*

How are we able to predict that there are 10^{80} atoms in the Universe? (Alexander – Year 9)

I thought I would do my own little 'back of the envelope' calculation, to estimate the number of atoms in the Universe. The result I got was less accurate than the number you state, but isn't *too* far off.

Here's what I did: I assume that all the mass in a solar system is contained within the star (this is a pretty good approximation. In our own solar system for example, the sun is 1000 times more massive than the most massive planet, Jupiter). Our sun has a mass of 10^{30} kg (that's a 1 with 30 zeros after it). Then, by assuming all the mass in the sun is hydrogen, I can divide the mass of the sun by the mass of a hydrogen atom (around 10^{-27} kg) to conclude that the sun contains about 10^{57} atoms. I know that our next nearest star, Proxima Centauri, is about 4.2 Lightyears away, so roughly 10^{16} meters. I can then work out a crude estimate for the average density of the galaxy to be 10^{9} atoms per cubic metre. Assuming this is the density for the whole Universe, I can multiply by the volume of the observable Universe (about 10^{75} cubic metres) to get a very rough (over)estimate of 10^{84} atoms in the Universe. There are lots of assumptions here that can be improved upon, some of which I didn't state (try and spot them yourself and think about how you could improve upon them!), and I've no doubt the 10^{80} figure you give used a much more sophisticated calculation. I also haven't justified exactly how we get the numbers like 4.2 Ly to Proxima Centauri, or the volume of the observable Universe. Each of these have their own experimental determinations, which are just as interesting to think about! – *Rob*

How do we know the diameter of the planets? (Grace – Year 9)

For the planets in our own solar system, this is not too hard to do! In fact, the first question on the Problem Page is a project you can have a go at yourself to measure the size of the moon!
For planets in our own solar system if you have a good enough telescope, you can measure the angle the planet makes in the sky and the use some simple trigonometry, and knowledge of the planet in questions distance from us to deduce its diameter.
For planets outside of our solar system, going around different stars to the sun (known as exoplanets) things are much harder! One way we can do this is via the 'transit method'. This involves measuring the brightness of a given star, and looking for regular 'dips' in the brightness. These dips are due to a planet passing between us and the star. From the width of the dip, we can infer the diameter of the planet! (Subject to many difficulties in measurement, and uncertainties.) - *Rob*

Will we be able to live on another planet in the future? (Evie – Year 9)

Humans are adaptable and are great at surviving in the most inhospitable of places. From dry deserts to icy cold tundra, humans have managed to live and even thrive in the most unlikely of places. The reality is though that, despite all this, unless the planet has a breathable atmosphere and mild temperatures, then we won't be able to survive on them unaided. So, in our solar system, we'll only be able to live on other planets like humans currently live in the ISS, with frequent resupply trips and sophisticated habitat control. But, it's not impossible that if we find another planet with a similar atmosphere and climate then we can adapt, grow and thrive as we have managed here on Earth. – *Tim South (MEng Aerospace Engineering, Bristol University 2019)*

Are there any other planets that exist in the solar system that we don't know about? (Jessica – Year 9)

Unsurprisingly, the true answer to this question is that we do not know. However, there are some clues that suggest there may be at least one planet beyond Neptune. All the known planets and most asteroids and mini-planets have a circular, or slightly elliptical orbit around the Sun. However, some asteroids in a region beyond Pluto called the Kuiper belt have large perturbed orbits, suggesting these objects have been displaced by a planet beyond Pluto with a sufficiently strong gravitational pull. Although this planet hasn't been found yet, astronomers can use measurements of the Kuiper belt orbits to try and determine where it is. – *Paul*

Black Hole Bonanza: **What is a black hole? How strong is the gravitational field in our nearest black hole? Could you fit a black hole into a container and if so, what would happen? (Lily, Daniel, William & Emily - Year 9)**

There was a lot of interest about black holes (understandably so!), therefore I've merged all three questions into one that I will answer in parts.

Roughly speaking, a black hole is the result of an unstoppable gravitational collapse. Formed when an object (generally a very large star) is so massive, that no other forces of nature (repulsion of its electrons or its nuclei) can stop it collapsing in on itself. These objects were first seriously predicted a few years after Einstein published his theory of gravity (general relativity). The anatomy of a black hole as described by general relativity includes a point of infinite density known as a 'space-time singularity' at the black holes centre. This singularity is enclosed within the 'event horizon', the spherical boundary of the black hole, beyond which there is no return.

"Well, the thing about a Black Hole - it's main distinguishing feature - is it's black. And the thing about space, your basic space colour is black. So how are you s'posed to see them?"

The above quote is taken from an episode of 'Red Dwarf', and really hits the nail on the head in describing the difficulty of knowing our nearest black hole! To search for black holes, we must look for their effect on the space around them. This is usually through the way in which they bend the light from the distant stars behind them (as predicted by general relativity), or their interactions with their partner stars in binary star systems. As for the gravitational field of our nearest *known* black hole (V616 Monocerotis), if you were to stand on a hypothetical platform just on the edge of the black holes event horizon, I calculate the force you would feel to be about 10^{11} (100,000,000,000 or one hundred billion) times the force you feel on the surface of the Earth!

Fitting a black hole inside a container might sound bizarre at first, but in fact there's nothing stopping black holes being very tiny! The key line most people know about black holes, that 'nothing that falls in can escape, even light', suggests that black holes can only grow larger, and cannot shrink. But in fact, black holes *can* lose mass, by a process of radiation theorised by Stephen Hawking. When black holes radiate particles, their event horizon shrinks until they could hypothetically be small enough (albeit for a very short time, before disappearing entirely) to fit inside your lunch box! Don't try this at home. - *Rob*