KES Physics Newsletter

Spring term 2019

Timothy South

'Rocket Scientist'

Studied Physics, Government and Politics, Maths, Further maths (AS)

Reading Aerospace engineering at Bristol University

At KES 2008 - 2015

Last term I was working on a group project to design a satellite. Since I last wrote that has now all finished. We presented the design, did a poster Q&A and wrote a group and individual reports, so the last few weeks of term were quite hectic.

As for this term, I have been studying four subjects plus doing my Final Year Research Project. My four units are Advanced Space Systems, Advance Techniques in Multi-disciplinary Design, Statistical Pattern Recognition and Bio-Inspired Artificial Intelligence.

First, I'll acknowledge the elephant in the room, *"But Tim, you're studying Aerospace Engineering! What has statistics and A.I. got to do with that?"*. A valid question with a simple answer. They don't. This year I was allowed to choose any subject option in the engineering department as long as it was at the master's level. I think the more interesting of these two units is Bio-Inspired A.I, in which we look at how processes take place in the natural world, such as insect swarm communication or genetic mutation, and how these processes can be used in the design of learning machines.

In Advanced Techniques in Multi-disciplinary Design we look at different optimisation algorithms (some of which you might know if you do decision Maths) and how we can apply them to engineering problems. My favourite unit this term though, unsurprisingly, is Advanced Space Systems. Some of the content we have studied so far includes; reusable launchers, mission planning, and interplanetary transfer. I think, by now, I've earnt the title of "Rocket Scientist" so hopefully Rob will do me a favour and update my name and description.

Not much physics talk (I know) but I hope this was an informative read anyway and I look forward to telling you more about my degree next term in my final newsletter. Until then, study hard!

Zak Goble

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

Reading Physics at Manchester University

At KES 2010 - 2017

I'm Zak, and here's a picture of me with Brian Cox. That clearly makes me the most accomplished physicist here.

This term, I'm studying solid state physics, statistical mechanics, wave optics, complex variables and energy sources. Statistical mechanics is mainly about probability, involving the chances of physical systems being in a certain state at any one time. Our lecturer for it has a stutter and loves swearing unexpectedly and dramatically in lectures, and for those reasons, he's probably the lecturer we pay the most attention to. If only school teachers did that.

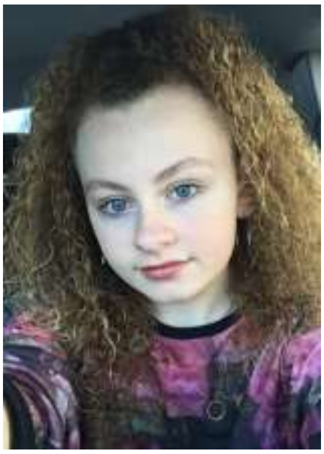
For wave optics, our lecturer is an elderly, camp, overly exuberant Sheldon Cooper-type legend. To sum him up in one word, it could only be 'fabulous.' He dances around the front of the theatre like nobody's watching when explaining anything, despite the three hundred physicists directly in front of him.

Nobody has a clue what's going on in solid state physics. It's too hard. Atoms, maybe? Or possibly something about energy? Yeah, one of them.

The energy sources course delves into the relative merits and demerits of the different energy sources, like fossil fuels and nuclear, but compared to GCSE level, it's very mathematical. You can also calculate how much energy a car uses by considering it as a cylinder moving through air, assuming, naturally, that all cars are perfect cylinders. It's almost as ridiculous as Fin getting kicked out of MooMoos for having dirty shoes.

Complex variables is my final course, taught by a real life wizard with long grey hear and a full beard. Unfortunately, he speaks at the speed of a turtle. I have to podcast him at double speed just to make him sound normal. A complex variable is something involving the square root of minus one. No such real number actually exists, so it's creatively named the 'imaginary' number. Weird and wonderful graphs are produced when functions of complex variables are taken, and they're really applicable in the real world. Just like everything you spend ten years learning at school and university. Everything.

Zak



Hi everyone! I'm now way into my second semester of Mechanical Engineering with a new set of modules but of course I'm never going to be able to get away from … MATHS! Unfortunately you can't just run away from calculus once A-levels are over, it catches up with you and reminds you how ridiculous you are for forgetting the dreaded +C (Yep, I still forget it even after all this time). As exhilarating as maths is I think I may, by the very smallest of margins, prefer my Manufacturing module. For this module we have been able to do a lot more practical work. If you read my last article you'd know about my tendency to be just a tiny bit clumsy so being let loose to use dangerous looking machinery was great fun. We were given the opportunity to use milling machines, laser cutters and lathes. Sadly, it's not as simple as just messing around with a machine and suddenly a completed part is produced, we had to learn how to use software to program the machine to do what we ask. In this case I was handed a yellow piece of acrylic so I clearly had no other choice but to program the milling machine to engrave a Homer Simpson onto it. When using the lathe no programming was necessary but if you wanted to maintain all of your fingers and prevent being hit in the face by flying scraps of metal a slight bit of attentiveness is required (The prospect of losing fingers is still more appealing than calculus). We made this vice all from scratch using a combination of the milling machine and the lathe, even the thread of the bolt. So to conclude the perks of choosing engineering is you can engrave your own Homer and make your own super cool mini vice, oh and learn some fundamental skills that will help you in the future when designing and manufacturing a product but you know I think the Homer probably tops that. Regrettably I've babbled too long so I've run out of space to update you all on the most recent episode of "Trin does stupid things" hopefully next time, but I can assure you it's stupid and involves me having 50+ Pot Noodles propelled at my car whilst I was driving.

Trinity Wills

Studied Physics, Maths, Art

Reading Mechanical engineering at Hertfordshire University

At KES 2011 - 2018

George Watkins

Studied Physics, Chemistry, Maths

Reading Astrophysics at Queen Mary University of London

At KES 2008 - 2015

This semester, I have been studying exoplanets and astrophysical discs, and the galaxy. The exoplanets module has been interesting, with an in-depth description of the various exoplanet detection methods, astrobiology and the search for life, and the structure of astrophysical discs. The galaxy module has also been very interesting, and I have learned about the various characteristics of spiral and elliptical galaxies, as well as stellar dynamics. I learned more about the all-important "*virial theorem*" and was shown how to formally derive it. This theorem provides a simple relation between the total potential and kinetic energies of stars within a galaxy that have settled into a steady state. I am just about to start discussing gravitational lensing and dark matter within the galactic halo, which is very exciting.

As I only have two modules this semester, the primary focus for me has been finishing my final year research project. Building upon my existing code, I have expanded the scope of the project, developing algorithms such that data can be downloaded, processed and modelled completely automatically. This has allowed me to download data for a large set of systems and analyse various characteristics of the dataset. I have been able to analyse the frequency distribution of planets, as a function of their radii, and have also been able to start looking into determining a mass-radius relationship for these planets. Determining this relationship (or relationships), and comparing with existing data, could lead to inferences being made regarding the structure of these planets.

Of course, a major part of the project has been the dissertation, which is most definitely not something I've considered to be fun or exciting. However, it really does help develop report writing and other associated skills. These are highly desirable skills, not only in science, but throughout many different sectors in industry. Many jobs, especially those related to analysis, often require reports to discuss various projects. The dissertation is great practice for structured writing, using and citing sources, and general communication. This is yet another example of how a degree in physics (or any STEM subject) provides skills for a multitude of careers, even if you don't want to go into research.

Robert Clemenson

Studied Physics, Chemistry, Maths, Further maths

Reading Physics at Oxford University

At KES 2008 - 2015

This term has undoubtedly been one of my busiest non-exam terms yet! I have had lectures in general relativity, condensed matter physics, and subatomic (nuclear and particle) physics.

Alongside lectures, I have been writing a proposal for the research I mentioned in the last issue. If I am successful in getting funding, I will spend another 10 weeks this summer at Caltech, working in an area known as AdS/CFT duality. This is widely regarded as a promising approach towards a quantum theory of gravity. (I will tell you more about this in the next issue, if I am successful in getting the required funds!)

I have also been working on a paper with two cosmologists in the physics department. We have been exploring the mathematical underpinnings of how cosmological models are verified by observation. So called 'likelihood functions' in cosmology, can tell us the probability of a certain theoretical cosmological model being correct, given the kinds of observations made (the observations we are using, are surveys measuring weak gravitational lensing).

Gravitational lensing is a phenomena predicted by Einstein's theory of general relativity. We observe that the light from distant stars is deflected by massive objects (such as other stars, black holes or galaxies). From what we know about Newton's law of gravity, this shouldn't happen. Newton tells us that gravity is a long range attractive force between objects with mass. However, photons of light are massless. Was Newton wrong?

Well, yes and no. Physics is all about building models, and knowing when it is your model works, and when it doesn't. Newtonian gravity allowed us to put men on the moon and calculate the orbits of the planets (except for a little subtlety in Mercury's orbit Einstein later fixed).

Newton's theory of gravity is not equipped to deal with the interaction of light and gravitation. Instead of an attractive force between massive objects, Einstein tells us gravity is in fact a bending of space. And the path taken by light in the presence of matter, is the path that maximises the space-time length in this curved space.

Paul Jarvis

Studied Physics, Chemistry, Maths, Biology

Read BA and MSci Natural Sciences at Cambridge University

Ph.D. in Geology from Bristol University

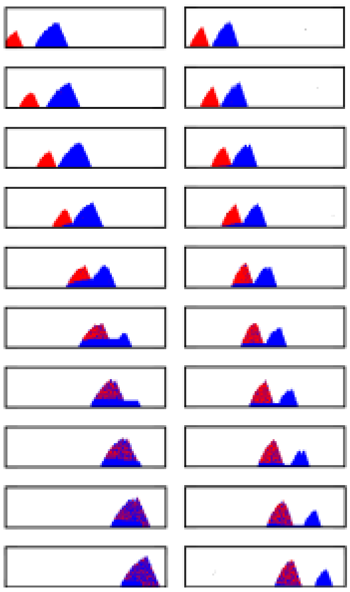
Currently a post-doctoral research assistant at the University of Geneva

At KES 2001 - 2008

Sand dunes are impressive features found in deserts, on coastlines and underwater. Studying their migration and evolution allows us to make predictions about, for example, how desertification may progress, or sea floor morphology may change which can have implications for shipping channels or flooding potential.

One of the most striking types of dune are barchan dunes, isolated bodies of sand that migrate over un-erodible bedrock. For a fixed wind, the migration speed is approximately inversely proportional to their height meaning smaller dunes migrate faster. Therefore, if you have a field of dunes in a desert, or a chain of them in a river channel, collisions will occur between dunes of different sizes. These collisions can have different outcomes, with the dunes either coalescing, or forming an intermediate structure before separating again. Recently, I have been working with colleagues to understand what determines the outcome of dune collisions.

We use computer simulations to reproduce the dune collisions. The benefits of this method are that, unlike in nature, we can perfectly control the conditions and produce hundreds of simulations within a few days. The figure shows two simulations, with the smaller red dune chasing the leading blue dune.



The first result we found was that the outcome is primarily controlled by the size ratio *r* between the dunes.

Surprisingly, the actual outcome of the collision cannot be determined exactly; either outcome can occur for a given size ratio *r*. What we were able to determine though was the probability of coalescence. We found that the probability of coalescence *P* is given by

$$P = \frac{\{1 - \tanh[16(r - 0.506)]\}}{2}.$$

For those of you into maths, this is a hyperbolic tangent function and, as you can see, it is not a useless as you may have thought.

This semester my main body of work has been on my laboratory report. This is effectively the product of 11 weeks of two hour, 9am Monday morning labs, which were not very fun. Out of these 11 labs we were assigned a random experiment that we did, and had to write a full report on it. I was assigned probably the most simple experiment we did, which was an A level experiment, where the factors that affect resistance in a wire are investigated. The experiment went as follows; current of varying voltages is passed through the circuit and the potential difference across the wire and the current are recorded (Figure 1). The length of each of the four wires and the diameter is also recorded. I also used two different materials - nichrome and copper. Once the cross sectional area is calculated for each wire, the equation $R = {}^{\rho L}/_{A}$ is used. Surprisingly, the factors that affected resistance in the wire were length, cross sectional area and the material which it was made from.

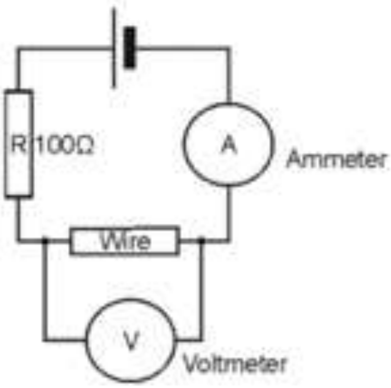
Fin Cooney

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

Reading Physics (with a foundation year) at Loughborough University

At KES 2011 - 2018

Although this was a tedious and fairly uninspiring experiment, I'm glad I did get it for my coursework as the theory is straight forward compared to some other experiments allowing me to still go into detail but with less hassle. Some of the other experiments I did were, Millikan's oil drop (which is actually very cool in practise), specific heat capacity of metals and also Boyle's law. I wasn't in the group doing the liquid nitrogen experiment which was a bit of a let-down, but hey ho.



Labs have been ok this and last semester, I only have them now for my two other modules, Mech Eng and Electronics, so I still have some practicals. My advice would be to attend every lab session as it is extremely easy marks to gain, even if they are 9am Monday, they're not that bad and you actually get to do some hands on physics.

I have also become a techno DJ which I would recommend, work hard for A levels, it's worth it for university.

I've spent the last few months of my PhD investigating how to control organic crystal growth through the addition of alcohols into the initial solution. You may find yourself wondering why anyone would want to do this, which I guess is a reasonable question. So, to recap from last term, the purpose of my PhD is to understand how organic crystals grow in the presence of different additives. This is an interesting topic because living things exploit crystal growth to form hard structures such as skeletons, teeth, shells, and so on. A good example of an organic crystal is calcite, which is very common here on Earth. Materials such as limestone and chalk are partially comprised of calcite. Many organisms like to use calcite (since it is so abundant) to form shells and exoskeletons. The problem with pure calcite, however, is that it is very brittle, making it quite useless for making structures for animals to use. Organisms combat this by including other elements in their crystals; for example, a certain type of starfish grows calcite crystals with the addition of magnesium-rich regions to form part of an endoskeleton. This improves the fracture strength of the crystal without altering its other properties. This is all reasonably well understood (although modelling this is actually another project I'm involved with), but the question of *how* the crystal grows still remains. It is already well established that the addition of other additives in the initial solution can change the crystal's properties, but we don't really know how. For example: some experimentalists recently found that the addition of ethanol in the calcium-carbonate-water solution eventually resulted in calcite crystals with different shapes, and also increased the inclusion of any other molecules in the solution. Recently, my job has been to make sense of all of this. Of course, we aren't able to zoom in on every single atom and look at what is going on. Therefore, to examine the atomic processes involved in crystallisation, I run computer simulations of the atoms present in the crystal/solution. Recently, I've been running simulations of calcite crystals in a solution of water and organics such methanol, ethanol and dioxane. I've used these simulations to examine the structure of the organics at the crystal surface, and how the presence of these different organics affect the growth of the crystal. Progress is slow, but by next time I should have some exciting results to share. Or some boring results. It's too early to tell.

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

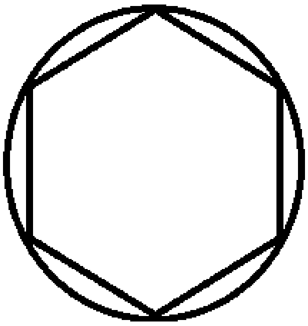
At KES 2012 - 2014

Problem Page

1) [All years] I want to figure out how to make a sheet of paper, such that the ratio of the longest side to the shortest side is unchanged no matter how many times I fold the paper in half (along the longest side). What ratio should the longest side to the shortest side be in?

2) [Year 11 +] Find a general expression for the area of an n-sided regular polygon embedded inside of a circle of unit radius. What happens as n becomes very large? Think about what *should* happen, before going through the algebra. You may find the following identity useful for the case of large n:

$$\sin(x) \approx x, for\ x\ much\ smaller\ than\ 1$$



E.g. A regular hexagon

3) [Year 12 +] When I drop a pen onto the ground, from around waist height, by how much does the Earth move in response?

4) [Year 12 +] Prove that:

$$2^n = \binom{n}{0} + \binom{n}{1} + \binom{n}{2} + \cdots + \binom{n}{n}, where\ \binom{n}{r} = nCr = \frac{n!}{r!\,(n-r)!}$$

(The terms in brackets are binomial coefficients)

5) [Year 12 +] The radius of the moon is about ¼ the radius of the Earth. Estimate the strength of gravity on the surface of the moon. What are your assumptions?

Once you have attempted all the problems, ask Miss Heggie for the solution sheet!

Questions and Answers

How will cars be powered once oil runs out?

There are already moves afoot to try and phase out cars powered by traditional petrol and diesel. The UK and France have both committed to banning the sale of new petrol and diesel cars by 2040. Car manufacturers are also exploring alternatives; all new cars from Volvo will be partially or completely battery powered this year. However, the driving force behind these moves is not the limited availability of oil, but rather the environmental impact of emissions from fossil fuel powered cars. Levels of air pollution in many major cities around the world, including London, are well above legal limits, largely due to particulates and fumes produced by combustion of fuel in car engines. Additionally, vehicles are the UK's largest source of greenhouse gases, and therefore a big driver of human-induced global warming. Therefore, unless we rapidly develop alternative energy sources for cars, both local and global impacts of pollution will have life changing impacts for all of us.

The most widely discussed alternative to petrol and diesel is electric cars which run on rechargeable batteries. Current technology though means the mileage between charges is fairly short, and frequent recharging is required. For this reason, hybrid cars, a combination of electric and traditional fuel, are also used. Whilst both electric and hybrid cars are already available, they currently make up a small percentage of the market. People still want powerful cars that they can drive for long distances without having to re-fuel.

Another option are hydrogen fuel cells where hydrogen is reacted with oxygen to produce water. This extremely exothermic reaction produces enough heat to power the car for approximately 300 miles with a single tank and since water is the only emission the cars themselves are much better for the environment. However, the cells are expensive and hydrogen is difficult to store safely. Nethertheless, multiple car manufacturers are investing into research in this area.

The biggest problem with both methods is that, whilst the cars themselves produce much lower environment emissions, the processes by which the electricity and hydrogen are generated in the first place still have significant environmental impacts. Hence, electric and hydrogen powered cars will only be better for the environment if we also start to properly invest in developing various renewable, and possibly nuclear, sources of energy on a global scale. – *Paul*

Is a human trip to Mars viable and what would be the biggest obstacles?

We currently have many of the technological capabilities to fly humans to Mars. What we currently struggle with is whether they could survive the trip. Radiation is a major issue in deep space and the best ways of protecting humans from it are largely impractical for spaceflight. There are also concerns with the long-term effects on the human body from spending an extended period in low gravity (a proper mission would likely be around 2 years long). This is why the ISS is so useful as it allows us to learn about the physiology of humans in space with relative safety. The biggest obstacles, however, are political will and finance. After all, someone will have to pay for it, and it will probably be the taxpayer so convincing politicians a human trip to Mars is worth it is quite the challenge. – *Tim*

What is dark matter?

The short answer is, we don't know!

When we look at the rotation curves of galaxies (a plot of the speed of stars orbiting their galactic centre, against the distance of those stars from the centre), the shape of the curve doesn't correspond to what we would expect to see if the only matter present is the matter we can *see* in the galaxy (stars, dust, gas etc).

Astronomers interpret this discrepancy as being due to the presence of invisible extra matter (invisible = not/barely interacting with EM radiation). As to the nature of this extra matter (i.e. what is a 'dark matter particle'), the particle physicists are none the wiser! They are given the generic title of 'WIMPs' (Weakly Interacting Massive Particles), and there are a few candidates for what specific hypothetical particles may be responsible, but any kind of experimental verification is a long way off. (Because WIMPs are so *weakly* interacting, they are unlikely to interact with detectors. The LHC has, as of yet, found no evidence for the existence of any of the WIMP candidates.)

To make things even more uncertain, not every physicist even agrees that dark matter exists at all! There are somewhat less mainstream ideas that the oddness we see in galaxy rotation curves is due to a failing of our understanding of gravity. For those interested, the Wikipedia page for 'Modified Newtonian Dynamics' (MOND) is rather good! – *Rob*

Could we reduce carbon dioxide in the atmosphere by having large solar powered drones in the upper atmosphere, with trees on?

No. Let me give a few reasons why:

1) **It's very cold in the upper atmosphere so those trees have probably frozen to death.**
2) **It doesn't really rain above the clouds, so those trees have probably died of thirst.**
3) **There isn't as much Oxygen, CO2 or really much air at all in the upper atmosphere so those trees have probably suffocated.**
4) **The power required to fly a drone, let alone with a payload, is far more than a drone size solar panel could produce.**
5) **It wouldn't work at night.**
6) **The possibility of shutting Gatwick airport.**

I think a better idea would be to plant more trees and use more solar panels but in a separate capacity. – *Tim*

Can you summarise the Pauli Exclusion Principle of nuclear stability? How does it affect beta emission?

So, the Exclusion Principle does most certainly play a role in the nucleus of atoms (and in whether it is energetically favourable for a nucleus to undergo beta decay), but it does so in a rather more complicated way than it does for the electrons orbiting the nucleus. I hope the questioner will forgive me for discussing the latter, rather than the former! (Look into the 'nuclear shell model', and the 'semi-empirical mass formula', if you're feeling brave!).

Pauli's Exclusion Principle, as a statement tells us: No two identical fermions (particles with half odd integer spin. i.e. spin ½, spin 3/2, ...) can occupy the same 'quantum state'. If there is a way to understand this, without going into the full machinery of symmetric and antisymmetric eigenstates of the parity operator in quantum mechanics, and the spin statistics theorem... I haven't found it! Fundamentally, this is a quantum mechanical effect, and not something we can apply out ordinary 'macroscopic' intuition to. But we can describe a few of the consequences of this statement for electrons orbiting a nucleus.

If you study A-level chemistry, you'll know a bit about the shell and subshell models of electronic configuration. The shell and subshell an electron occupies is summarised by the energy level n, and the subshell

label s, p, d, f. There is a hidden label in this notation, which classically roughly corresponds to the direction the electron is spinning around the nucleus. These three labels very nearly describe the full quantum state of the electron. Depending which subshell an electron is in, there are a different number of possible ways the electron can orbit around the nucleus. For s there is only 1 way (1 state), for p there are 3 ways (3 states), for d there are 5 ways (5 states), and for f there are 7 ways (7 states). Which, given the exclusion principle tells us we are only allowed '1 electron per quantum state', might lead us to think that the s subshell can fit 1 electron inside, p fits 3, d fits 5, and f fits 7. But this is not what we observe (and should seem wrong to the A-level chemists).

We have not included the spin of the electron in our consideration. You may have heard the term 'spin pairing' in your chemistry lessons. When drawing diagrams for electron configuration, per orbital you draw one little up arrow, and another little down arrow. These arrows represent the two possible configurations of the electrons spin (*sort of* like the direction in which the electron is spinning about its own axis). With these two additional possible quantum states, we have: s fits 2, p fits 6, d fits 10, f fits 14. In agreement with what we know about chemistry!

If the exclusion principle didn't apply to electrons, all unexcited atoms would have all of their electrons in the ground energy level 1s. The fact that the number of electrons per level (occupation number) has a limit, due to the exclusion principle, gives us all of the interesting chemistry that allows life to exist.

As a point of interest... Bosons (particles with integer spin. i.e. spin 0, spin 1, spin 2, ...) are not restricted by the exclusion principle. Which means under certain conditions, a large group of bosons can all fall into the same quantum state, which gives them very strange properties. (Look up superfluid helium, and Bose-Einstein condensates) - Rob

Submit questions for next terms issue to Miss Heggie!