KES Physics Newsletter

Spring Term 2021

Figure: The Veil 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! You can find answers to some of your submitted questions on pages 8 - 10.

Wishing you all a very happy easter 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

Evie on Mt. Etna, during a less-explosive time.

Paroxysmal eruption at Mt. Etna on 16/02/2021.

Mt. Etna, Italy, is one of the world's most active volcanoes, almost always producing some style of eruption. However, since 16th February 2021, it has produced an unusually spectacular sequence of explosions almost every two-to-three days. These so-called paroxysmal eruptions are associated with large ash plumes, stunning lava-fountains and lava flows. The physics of how and why these eruptions occur is fascinating and I recently spoke to Evie Snee, a PhD student in volcanology from Cardiff University who studies Mt. Etna, about the eruptions and how she got into volcanology.

How did you become a volcanology PhD student?

I first became interested in volcanoes from a family holiday to Tenerife. I was interested in the rocks and about the volcano Mt. Teide. After this, I studied Geography, Geology and Maths at A-level, and then did an MSci. degree in Geology at the University of Bristol, including a year abroad in New Zealand. For the past four years I have been working on my PhD which is focussed specifically on of dynamics ash coupled with lava fountains at Mt. Etna. I've been fortunate enough to visit Mt. Etna, Stromboli volcano (Italy), Geneva and California as part of my work.

What is currently happening at Mt. Etna?

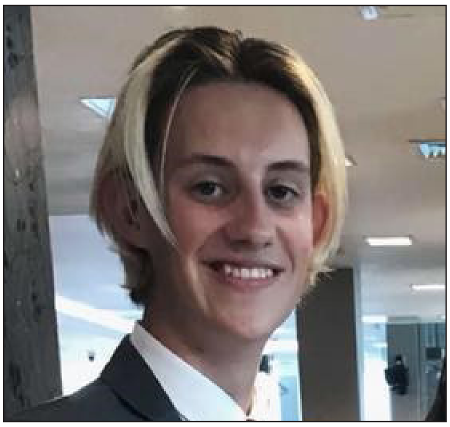
Currently, Mt. Etna is producing frequent paroxysmal eruptions which means it is producing both an ash plume and a lava fountain. The lava fountains can reach heights up to 1.5 km above the vent whilst the plumes can reach approximately 10 km above sea level and have caused ash fallout to the local communities.

How do you study these eruptions?

I study these eruptions through numerical modelling. I use simple integral plume models along with observations of the plume to try and better understand the dynamics of these eruptions. I do this by writing computer code to solve the equations which describe the fluid dynamics of the plume, as well as performing image analysis on videos of the eruption. I try to understand processes such as coupling between the lava fountain and the tephra plume and sedimentation.

Is the current eruption dangerous?

Generally, no. Fortunately, the majority of the population does not live close to the vent. While ash fall can be problematic for the local communities, generally it does not pose a significant hazard here. However, I wouldn't recommend getting to close as volcanic bombs and pyroclastic density currents can occur!



Fin Cooney

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

Reading Physics at Loughborough University

At KES 2011 - 2018

This term we have started looking into the applications of our acquired knowledge from last semester. Last semester we looked at Quantum Mechanics in detail, this semester we have begun our study of what is known as solid-state physics. Solid-state physics is effectively the study of how large scale or macroscopic properties emerge as a result of atomic properties. It is effectively scaled up quantum mechanics and just interesting. The application of this branch of physics is vast and is responsible for a lot of the modern world. For example, knowledge of solid-state physics is essential for designing and building transistors, meaning that without solid state physics it would be unlikely we would have much of the technology around us today.

In our labs this term we have been looking at designing and inventing products as well as how to patent inventions. Our main project is a group task which involves us creating 5 identical devices which can autonomously measure two parameters. We are then going to take these home at easter and each collect results. My groups will most likely be a humidity and temperature sensor which will be created using Arduino.

One of my other modules is Astrophysics and Astronomy. This is probably has been my favourite module after Quantum Mechanics. We study the structure and lifecycles of objects in the universe and also get time to use the University's telescope – this was pretty cool.

We also do a computational physics module, in which we have been using a piece of software called COMSOL. COMSOL is a Multiphysics simulator. It has a wide variety of applications. We use it to solve differential equation as well as modelling different experiments.

Albert Haladay

Studied Physics, Maths, Computing, Further Maths

Reading Theoretical Physics at Nottingham University

At KES 2013 - 2020

I am in the second semester of my first year, since the last time I have written about my experiences I have learned a whole lot, the module that encapsulates relativity has rapidly increased in difficulty. In this module we have studied the basics of the light clock, and how to derive the time dilation equation; this was especially interesting as with just a thought experiment I found out that you could deduce so much. We also covered various paradoxes like the twin paradox and Einstein's train paradox, which until the answers were revealed were incredibly mind boggling. Another thing I learned was Lorentz contraction! It feels and sounds insane that as you speed up distances will contract and become smaller, and it was something I never knew.

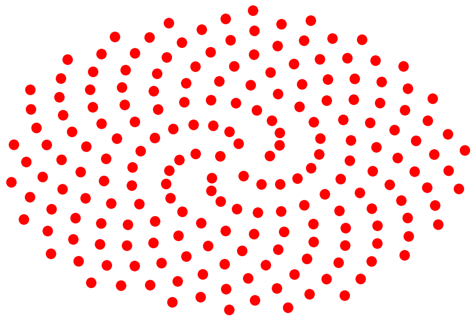
I also started my module on Dark Matter, previously I always thought that Dark Matter was some mysterious unknown to the world of physics, and I never had a clue what people meant when they spoke of it. From what I understand so far, we can use the doppler effect to see how fast some stars in spiral galaxies are moving, but the centripetal force holding them in is much greater than it should be, hence we know there must be mass there that does not interact with light. That is what we call Dark Matter, I still have absolutely no idea about Dark Energy though, that is still to come.
In sharp contrast to my last entry in this newsletter, the Mathematics for Physics module has been a struggle for survival, differential equations are not your friend. Even more so for me since I missed most of the differential equations part of A-level Further Maths due to covid-19. They are quite the pain to learn, but now that I have got to grips with them, they seem to be steadily getting easier.

The experimental physics module has remained to be difficult under the current circumstances but will soon be finishing just after the easter break. To accompany the formal reports that I am making in this module I recently started learning LaTeX, which is a programming language for typesetting documents, and has been invaluable when trying to make my reports look professional.

The computing module has remained the same, the content is still going over the basics. However, the exercises are very fun to make, such as creating Fermat spirals and Barnsley Fern Fractals, if you have any background in programming, I highly encourage you to try these since they aren't all that hard.

The Barnsley Fern Fractal

A Fermat Spiral



Alex Broad

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

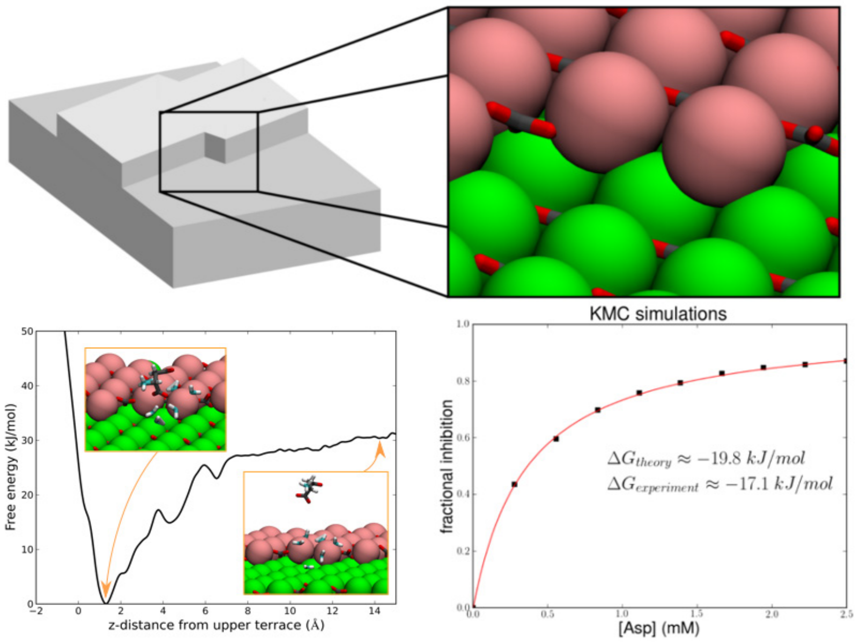
Read BSc Physics at Swansea University

Read MSc Physics at UCL

Physics Ph.D. student at UCL

At KES 2012 - 2014

When wrote my last entry for this newsletter I was talking about some previous work I did about a year ago. I did this for two reasons: 1) I thought it was worth sharing; 2) I had literally nothing else to write about. This was mostly because I was working on a new, seemingly impossible project where I was attempting to replicate some experimental work on adsorption of aspartate at calcite growth sites. The purpose of this was to better understand how additives, in this case aspartate, shape calcite growth. The reason this project was taking me so long is because replicating real world conditions is an incredibly complex task. First of all, calculating binding energies for individual growth sites is complex. Second, lots of different growth sites exist, each with their own binding energy and likelihood of existing. Directly simulating the process is impossible with current computers. However, the process can be broken into stages. First, I pick an individual growth site, which you can see in the top of the figure. Second, I calculate its binding energy using molecular simulation (bottom left). Finally, I build a use the binding energies to derive a set of probabilities of attachment and plug these numbers into a Kinetic Monte Carlo (KMC) simulation. A KMC simulation basically works by lining up all possible reactions and picking one at random. When I do this, I can effectively run a "theoretical" experiment and compare with the actual experiment. This can be seen in the bottom right of the figure. My final results are compared with experimental findings and shown in the graph, There is a surprisingly good agreement between the two (it is actually very rare to find much quantitative agreement between experimental and modelling data). This result is really good because bridging gaps between experiments and modelling is a big open problem in crystallisation



Zak Goble

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

Reading Physics at Manchester University

At KES 2010 - 2017

I'm Zak, and I'm still riding on the success of being taught by Brian Cox despite it being 3 years ago.

This term, I'm studying exoplanets, stars & stellar evolution, early universe, and galaxy formation. Proper astronomy.

Exoplanets is the study of detecting planets beyond the solar system. Although nobody has worked out how to detect exoplanets directly yet, we can infer their presence by looking at the luminosity of distant stars over time. If the luminosity dips for a small while, it means an orbiting planet must have been in the way, blocking the light. We can also determine the size of that planet relative to the size of the host star by equating it to the fraction that the luminosity decreases by. This naturally assumes that God didn't randomly turn off the lights.

Stars and stellar evolution is exactly what it says on the tin. Unfortunately, because the lecturer hasn't yet worked out how to share his screen on Zoom without everything coming out incomprehensibly blurry, and can only ever reply with the line, 'it looks fine on my screen', we're yet to learn a thing about it. We presume it's something to do with stars and/or stellar evolution.

Early universe is a maths-heavy course centring on cosmology at very small times, when the universe was dominated by radiation and expansion with very little matter. In this, we look at the Hubble Law, which states that the speed at which objects in space move away from each other is proportional to their separation. This means that, at a particular distance, objects are actually moving away from each other faster than the speed of light, and that neither light nor any information from stars beyond that distance can ever reach the Earth. The distance is called the horizon. All of the dark patches on the night sky might not actually be dark at all, but instead filled with galaxies and stars just beyond the horizon.
Galaxy formation is our token impossible course this term due to its overreliance on tensors and index notation (which is a part of maths that only Rob understands).

Something that Rob doesn't understand, on the other hand, is dark matter, which is currently beyond the understanding of every physicist in the world.
We know something's there because the maths around galaxies is broken.
We know it's invisible and undetectable, and we know it must have mass, but beyond that? Absolutely no clue whatsoever.

Galaxy formation looks at how dark matter may have been created and where it might have come from.

Our exams were added to the growing list of things messed up by COVID this year. We've still got them, but they're all going to be in the comfort of our own homes – feet up, coffee in hand, surrounded by revision notes.

Which means I never have to go back to Manchester again. Hooray!

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

Well, hello again everyone! Another term is fast drawing to a close, and I really don't feel like much has happened in the last couple of months!

A few things that do come to mind:

1. In January, I started teaching in the maths department at my university - taking a few undergrad tutorials/workshops for first and second year students.

2. I've started livestreaming physics related content - including an office hour, where anybody can come and ask me questions live.

3. (Most excitingly!) I've organised two visiting research positions in the US. One at UC Berkeley, and one at UC Riverside. All things being well, I will be spending some period (at the moment the plan is 18 months) shared between these two institutions, collaborating with other researchers there.

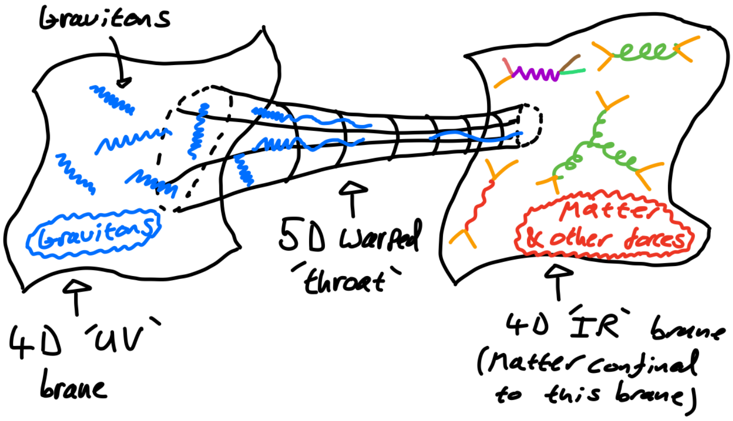
A central theme of my research, is the idea of extra dimensions. Extra dimensions have been a popular idea in theoretical physics for the last several decades, as they can be used to fix a plethora of unsolved problems in the standard model of particle physics.

One such problem, is the *hierarchy problem*. This problem describes the 'unnaturally' large difference in strengths of the weak nuclear force, and gravity. In the late 1990's, a resolution to this problem was proposed that relies on the existence of a single extra spacetime dimension (this is called the *Randall-Sundrum model*). Particularly, this fifth dimension is not flat but *warped*, and sandwiched between two *branes* (4D surfaces) as sketched. [Note: by 4D, I mean 3 space dimensions, and 1 time dimension]

In this construction, all the particles and forces excluding gravity are localized on one side of this 5D 'throat'. While gravity (specifically, *gravitons* - the hypothetical exchange particle of the gravitational force) is localized towards the other side of the throat.

The effect of the warped 5D throat, is that the gravitons which interact with the standard model particles (quarks, leptons etc) are stretched out and redshifted. This results in the apparent weakness of gravity compared to the other forces.

There are still a number of interesting problems with this model to consider. One we have been trying to understand recently, is the role that the strong nuclear force might play in stabilizing the length of the throat, sandwiched between the two branes.



Questions and Answers

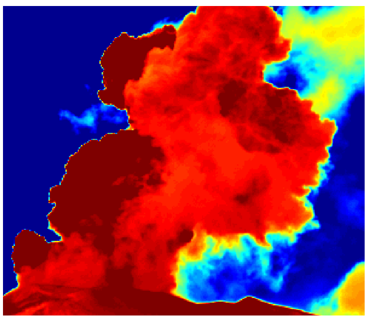
Submit your questions to Miss Heggie, or through the Cosmic Conundra contact page

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 the best physics project you've ever participated in? (Year 12)

The best physics project I have ever participated in involves a combination of field work at an erupting volcano, image analysis using infrared cameras, and solving the equations of fluid dynamics to determine how much mass is erupted in a volcanic eruption.

First, some colleagues and I took a field trip to Sabancaya volcano, Peru, in 2018. Since 2016, Sabancaya has produced approximately 10-20 explosions daily. We took an infrared camera and captured thermal images of the eruption plumes. Then, we analysed the videos to calculate how fast the plumes rose above the volcano. Finally, we are using a theoretical model of the fluid dynamics of plumes to invert these rise velocities of the mass of erupted material.

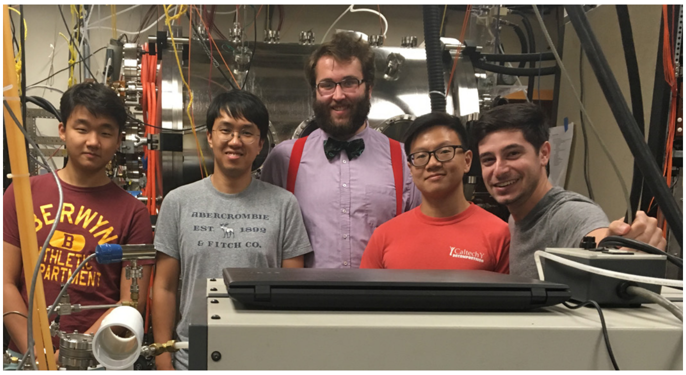


Paul Jarvis

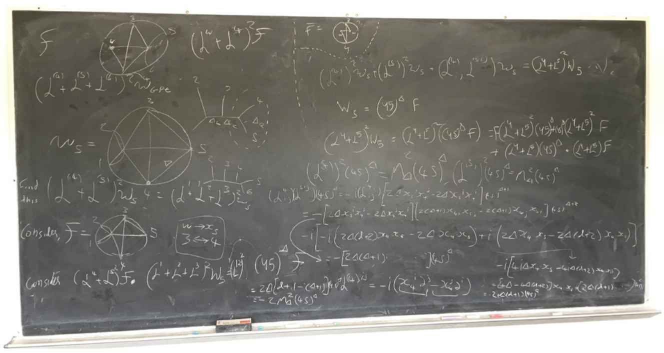
I've been lucky enough to be involved a couple of interesting projects during my career so far (and for my PhD at present!).

In 2018 I spent a few months working in a plasma physics lab at Caltech, funded by a NASA grant the professor I was working under had obtained. I was performing modifications to an experiment that is a replica of one experiment on the International Space Station (the PK-4 experiment). The modifications we made should some day be translated onto the ISS set up.

Then in 2019 I was back at Caltech in the maths department, working on a paper in an area of quantum gravity called the adS/CFT duality. The first week I was there, my supervisor very generously gave me a small problem to solve, that would be necessary for our later work. It wasn't an especially difficult problem, but it was one nobody had previously thought about. So when I eventually solved it, I just sort of sat and thought for a moment; 'I'm the only person in the world that knows about this' - and that is always a profound and exciting moment for any scientist.



Part of the Bellan Plasma Physics Group



A few of my sums on a Caltech blackboard

Robert Clemenson

What are the advantages of choosing physics A level compared to the other sciences?
(Year 10)

In my opinion, the advantages are very strong! That of course isn't to say you shouldn't also pursue the other sciences... Three sciences and maths for A level is a very powerful combination, which leaves a great number of options open to you.

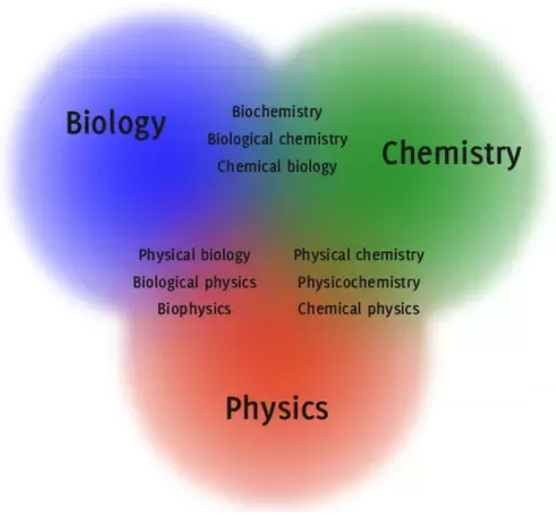
But if you twist my arm, and make me put one science A level above the others, I will of course always choose physics!

If you're not planning on going into a career in the sciences, physics can be a very useful single science subject. Demonstrating problem solving and analytic skills (which are desirable in nearly all jobs & degree programs), and moreover, a good competence with mathematics!

If you're interested in a number of the sciences, and might want to pursue one or more at university; a working knowledge of physics will benefit you enormously. Biologists, chemists, geologists, medics, etc all need a good working knowledge of physics.

If you're planning on going into engineering, computer science, maths, or physics for your degree/career; then a physis A level is of course something you can't do without. You should also note, that for all physics & engineering degrees, as well as many comp-sci degrees a maths A level will also be required.

Robert Clemenson



Why is physics so hard?
(Year 10)

I think that physics is hard for a number of reasons. I also think that the subject has a greater number of hard things about it than lots of other subjects which is why it along with other stem subjects like engineering and maths get a bad name.

Take for example history, which I did at A-Level. History is hard as you have to contextualise events that happened long ago and then see the implications, causes and consequences of different events. Although this is a slight simplification of an entire branch of the humanities, this is the gist of studying history.

With a subject like physics, you're constantly building on top of your prior knowledge to get more of an understanding of things that aren't necessarily intuitive or easy to simplify. Physics hits you at a number of different directions. You need to be a good critical thinker, be good at maths, be good at conceptualising things that are hard to conceptualise, and you also need to be able to spot patterns in problems and recognise where to implement what you already know.

This isn't to say that history is easy (it's not) but compared to a subject like physics, which is so abstract compared to other subjects, it seems it. Physics relies on the fact that you already know so much about the subject that the things you learn on top to those that study it seem far simpler than to those who haven't studied it.

Say for example someone in year 7 wanted to understand what the annihilation and creation operators were (this is part of QM that we learnt about last semester). They would have to learn and understand all the physics that I and other undergrads have learnt up until second year QM in order to get fully understand it. You can't just go straight into the hard stuff – this is why it has its reputation.

To bring up the history example, say if a year 7 wanted to learn about degree level history, in my opinion the gap in knowledge required to understand it would not be as great. You could still learn about the events, causes and the consequences.

Fin Cooney

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Can you explain black holes and wormholes in a simple way so even I can understand them? Do they even exist? (Year 10)

Both of these objects are still very mysterious. In terms of observation - we have very strong evidence that black holes exist in the Universe. For wormholes however, we have no observational evidence - so the jury is still out!

There are two significant parts to the anatomy of a black hole. The 'horizon' - which divides the rest of the Universe from the interior of the black hole, and the 'singularity' - a point of infinite density at the centre, where the entire mass of the black hole is concentrated.

Black holes have all sorts of fascinating properties. They are a prediction of Einstein's theory of gravity (general relativity), which tells us that strong gravitational fields can slow the passage of time experienced by those in them. The gravity near a black hole is incredibly strong, and therefore so are the time warping effects they induce (like in the film Interstellar).

An interesting consequence of this time warping can be seen in comparing the experiences of two people outside of the black hole: Alice, who is sat far away from the black hole looking towards it, and Bob who is freely falling towards the black hole, pulled in by its gravity. From Bob's perspective, he will fall in towards the black hole, and cross the horizon (the outer edge of the black hole) in a finite period of time. Alice on the other hand who is watching Bob fall in from afar, would see Bob fall towards the horizon slower and slower, but never actually cross it.

This is a bizarre prediction. From Bob's point of view, he will cross the horizon of the black hole in a finite amount of time. But from Alice's perspective, it will take Bob and infinite amount of time to pass through the horizon of the black hole. This illustrates one of Einstein's great revelations - that there is no such thing as absolute time. The time between events, depends on who is making the measurement (specifically - how fast they're moving, and how strong the gravity is where they are).

I've written a little more about wormholes on the Questions & Answers page online, as mentioned at the start of this section.

Robert Clemenson

What are the best revision websites for A level Physics? (Year 12)

Here are a few good websites & YouTube channels I recommend:

www.physicsandmathstutor.com

isaacphysics.org

YouTube - DrPhysicsA

YouTube - PhysicsOnline

(You can open these as hyperlinks in the PDF form of the newsletter)

Robert Clemenson

Are all physics students at uni nerds and geeks? (Year 10)

The definition of a nerd is, "a foolish or contemptible person who lacks social skills or is boringly studious". By this definition, I don't think you will find anyone at university who hasn't been foolish, lacked social skills or been studious at some point. If you go to University or do you're A-Levels chances are that you will have to put in a shift to get a good grade. The same is true with GCSEs – there is nothing wrong with being into your subject.

Having said this the stereotype that all physics are nerds in my opinion is false. I think that all physicists are intelligent but what I don't think is that all physicists nerds due to that fact that there is a variety of different people on my course from lots of different background and there are people with a wide variety of interests other than physics.

A friend of mine on my course for example plays prop for Harlequins and stands at 6'4. I wouldn't consider him a nerd by the above definition.

Fin Cooney