KES Physics Newsletter

Summer Term 2021

Figure: The Spiral Planetary Nebula (NGC 5189)

Note from the Editor

Hello all! Thank you for reading each of this year's newsletters. It's been a challenging year for everyone, and I'm sure you've all been working very hard. As this is the last newsletter of the year, I'd like to thank Albert, Alex, Bradley, Callum, Fin, Paul, Tim, and Zak for the various contrbitutions they have made this year. I know their efforts are appreciated, and personally give me a lot of joy to read! Wishing you all a very happy (and restful!) summer break!

- Rob -

Alumni-Student Astrophotography

This section shows off some of the wonderful astrophotographs taken by former KES students - If you are a current student, and would like to submit a picture of the night sky for the next issue you can speak to Miss Heggie.

In this section, we see two kinds of object. *Galaxies*, and *Nebulae*. Galaxies are large clumps of stars, some containing more than 100 billion stars. Nebulae are the whisps of gas and dust, left behind when stars die. These nebulae also act as birthing grounds for new stars, formed from the ashes of those that came before.

Bradley Holloway

At KES 2012 - 2019

I have always been fascinated by the Universe. Last year I started taking photos of the night sky, and since upgrading my equipment I have been able to look deep into space. My proudest achievement so far is imaging a galaxy 150 million light-years away.

Callum Shingleton-Smith

At KES 2012 - 2019

I've been doing astro-photography for around a year now and it's been a fun journey - you can get some great images whatever the equipment you have (I started out with my phone camera). I recommend giving it a try - winter nights are good for clear skies providing the weather holds!

The Andromeda Galaxy - The nearest galaxy to our own, at a distance of 2.5 million light-years – Best seen in winter months. *Photo by Callum Shingleton-Smith*

The Whirlpool Galaxy - A spiral galaxy located 31 million light-years from Earth. NGC 5195 is a galaxy passing behind M51 tugging on its arm. *Photo by Bradley Holloway*

The Veil Nebula - A supernova remnant 2,100 light-years from Earth, left by a star about 20x the size of the sun which exploded over 10,000 years ago. *Photo by Bradley* Holloway

The Milky Way Galaxy – The outer edge of our own galaxy, home to our solar system and 100 bilion others. Best seen in summer months. *Photo by Callum Shingleton-Smith*

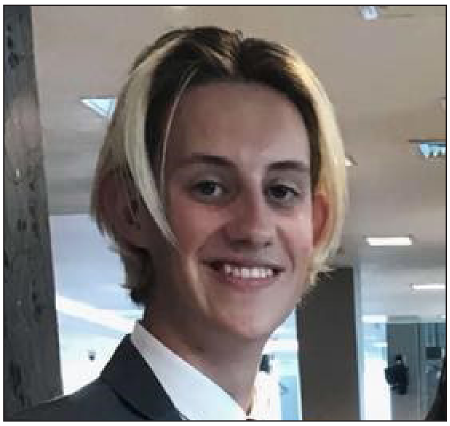
Goodbye Miss Heggie!

Without any shadow of a doubt, teachers play ***the*** most crucial role in science. Without them, the best scientists in the world would never have the interest to go forwards, and discover new and exciting things about the Universe. Miss Heggie has played such a big part in inspiring, motivating, and supporting all of us in this newsletter (and countless others!) that overlapped with her time at KES.

Miss H, from all of us writing this newsletter, we wish you the very best for the future, and thank you for your patience, kindness, and most of all for sharing your love of science!

Wherever you go next, we know you will bring your **P**ositive **P**hysics **A**ttitude with you!

- The Newsletter Team -



Fin Cooney

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

Reading Physics at Loughborough University

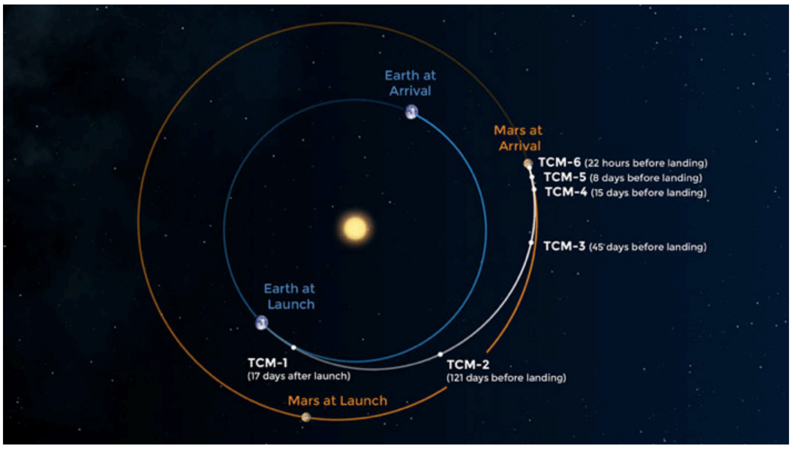
At KES 2011 - 2018

This term I have been looking at a variety of physics, maths and astronomy, each posing their own unique and often challenging trials and tribulations. Reflecting on the past academic year, I realise that the most obvious and poignant difference between first year and second, was the increase in workload. I did expect this to some extent, since my second year is worth 40% of my overall marks (third year is the other 60%) but was still surprised at how much work the Physics department expected of us especially during the pandemic. Having said this, the baptism of fire that was this year was still certainly enjoyable and the topics covered on the course were always interesting (with the exception of labs). Astronomy gave me insight into stella structure and evolution as well as a grasp of cosmological calculation, the progression of the universe as well as its beginnings and a variety of different atomical tools and techniques that can be used to deduce things about the universe and objects in it. We completed a portfolio that demonstrated the skills we learned over the course of the year as well as a report on a topic that we found interesting, mine was on the observation of pulsars.

In our main physics module this term involved solid state physics. This involved the study of ridged matter and expands on the idea of quantum mechanics, scaling up quantum to have many small systems being modelled as one. The main piece of coursework for this module was a look into analysis of x-ray diffraction (XRD) data. This piece was as interesting as it was challenging and gave me a wider appreciation for XRD. My maths module gave us a look into things such as special functions, ordinary differential equations (ODEs) and complex analysis. This culminated in two coursework style exams that were assessed recently.

Looking to final year I have begun researching and finalising my proposal for my final year project. We are expected to complete a 300-hour project on a topic from a given list of projects. One really stood out to me; a project centred around a field known as astrodynamics. This involves the study of how objects move through the universe and how we, as humans, can move between these objects on manned or unmanned vehicles. My project will likely involve a simulation of a ship that leaves earth on a given day and journeys to a planet or moon (probably mars). I will also look into the logistics and feasibility of sustaining life at the chosen destination long term.

Next year I'm looking forward to my modules such as dynamical systems, medical physics and thin film physics.



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

Much of my research in volcanoes focuses on the concept of stability and instability. When the magma storage region beneath a volcano becomes unstable, it can cause an eruption. This eruption, if explosive, might generate a volcanic ash plume which itself can become unstable, causing it to collapse and form a pyroclastic density current. However, it is not always obvious what we mean by the terms "stable" and "unstable".

A classic example used to explain the concept of stability is a pendulum. Imagine a pendulum hanging downwards (Figure 1a). This is an equilibrium position because, if no external forces are applied, the pendulum will not move. If you displace the pendulum by moving the bob to one side, the bob will swing back and, after oscillating a few times, return to its original position. Therefore, not only is the original configuration an equilibrium position, it is also a stable equilibrium because, if you make a small displacement, the pendulum returns to where it started.

Now imagine that the pendulum is instead pointing perfectly upwards (Figure 1b). It may be surprising but this too is an equilibrium position. If there were no external forces and the pendulum was perfectly made, the pendulum would stay still. However, in reality, small disturbances in the air and defects in the pendulum mean it would be impossible to position the pendulum like this in practice. In fact, this demonstrates that the upward-pointing pendulum is an unstable equilibrium because, if you displace it, even by a tiny amount, the displacement keeps growing until the pendulum hangs downward.

So, to wrap up this example, a stable configuration means, if you make a small change, the system will return to its original state. Alternatively, if the system is in an unstable configuration, a small disturbance will keep growing and the system can undergo a dramatic change until it reaches a new equilibrium. Such instabilities are important in many fields in physics. Figure 2 shows an experiment where a denser fluid has been placed above a lighter fluid. A barrier has initially separated the two layers and then been removed. A denser fluid overlying a light fluid is unstable and we can see the two fluids change positions through what is called the Rayleigh-Taylor instability. It turns out that this type of instability can happen in many different natural environments including volcanic clouds and magma chambers, oceans, and stars.

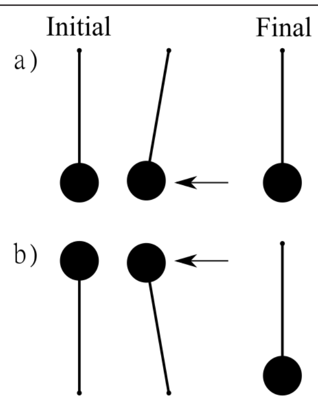


Figure 1

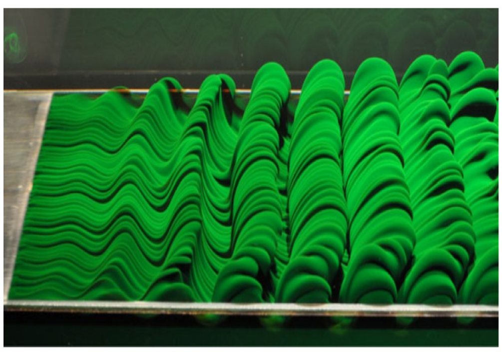


Figure 2

Zak Goble

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

Reading Physics at Manchester University

At KES 2010 - 2017

I'm Zak and I have just finished my degree, which means I am no longer exceeding the RDA of misery. As ever, while the infinitely wisdomous Rob requests three articles per year but Manchester only has two terms, this one will feature a no-filter explicit description of my lab life.

As my degree was a four-year integrated master's degree, instead of writing a dissertation at the end of our third year we had to complete a year-long master's project. This featured all the normal pleasures of lab – data handling, analysis, blindly attempting to make sense of an Excel spreadsheet full of random numbers – as well as a twenty-page thesis that took months to write. My project, titled, 'Darkness from light: producing dark matter from high-energy photon interactions at the LHC', had me once again delving into particle collision data from the Large Hadron Collider and statistical models in an attempt to discover the illusive dark matter particle.

Firstly, we looked at the monophoton channel. This is where the two colliding protons collide and form a photon (particle of light), which radiates an unknown high energy mediating particle which then decays dark matter particle-antiparticle pair. This one had been explored at the LHC before and, amongst the trillions of collision events over the several years the collider has been running for, they found zero of these specific events. Even with our huge efforts towards waking up and getting ready to work by 9am on two days per week, and spending weeks simply attempting to log in to the data servers (Linux sucks), we didn't find anything either. Our conclusion here, as is usual with dark matter studies, was, 'we found absolutely nothing and we're 95% sure about it.'

Secondly, we looked at a sector that hadn't been previously explored. This was the photon-photon fusion channel, where, instead of colliding, the initial protons exchange a pair of photons which fuse into the mediator which, as before, decays into the dark matter pair. Following analysis (that took us weeks) this one looked about 100 times more likely than the monophoton case, but limitations with the LHC detection methods meant that it was also about 100 times less likely to be detected. This meant that the expected outcome was about the same. Our work was of genuine scientific consequence as it suggested to the team working at the LHC that if the specific detection methods for the photon-photon fusion channel are able to be improved, it shows a lot of promise for future research towards the discovery of dark matter.

With my degree now finished, this shall be my final article. Cheers to Rob for organising everything and cheers to anyone that has read the rubbish I've spewed over the last four years.

One last message to everyone at KES:

See you at school next year innit.

Zak

Albert Haladay

Studied Physics, Maths, Computing, Further Maths

Reading Theoretical Physics at Nottingham University

At KES 2013 - 2020

This is the third article I have written for the KES physics newsletter, since my last entry I have experienced the first-year exams. Admittedly it was a stressful time but being under exam conditions helped me adapt to university style examination questions, which were dramatically different to A-Level and GCSE exam questions. In most of my exams this year there were six questions and I only had to answer four, which sounds easy but the questions themselves were very long winded and could be very challenging. Surprisingly enough covid restrictions did not affect the examinations much at all, the exams were open book and done at home. We were given an extra 30 minutes to scan in and submit our answers and that seemed to work quite well, personally I think the environment was a whole lot less stressful than a regular exam hall silence.

I also learned lots about electromagnetism and solidified my understanding of fields. Electromagnetic induction was also great to learn since I had previously heard of the concept, however using maths to derive Faraday's law allowed me to understand the relationship between the two a whole lot more. The general idea is that a changing magnetic field will create an electric field, and a changing electric field will create a magnetic field, this is also how electromagnetic waves propagate. Maxwell's equations were interesting and using them to derive the speed of an electromagnetic wave was incredibly eye-opening, since the method to do so was just a direct application of the equations on an electric and magnetic field that are both moving sinusoidally.

We also covered introductory quantum mechanics, which was not as bad as it sounds. The general idea was that small particles can be treated like probabilities. Although there is a lot of word soup like "the time-independent one-dimensional Schrödinger equation" and "quantum mechanical particles", the topic made some sense. Continuing from that I also learned about quantum mechanical tunnelling. In essence quantum mechanical tunnelling is just how a particle can pass through a barrier that would be impossible to pass according to classical physics, this is directly applied in a scanning tunnelling microscope. An STM detects electrons that have tunnelled from the surface of a conducting material to the tip of the STM, which allows the surface of the material to imaged, since the further away you are from the material, the less likely an electron will tunnel.

There was also a philosophical aspect to quantum mechanics as well which I found very interesting. For instance, "Laplace's Demon" was an article that previously posed the idea "If someone knew the location and momentum of every particle in the universe at one point in time, they could calculate the past and future position of every particle with the laws of classical mechanics.", which promotes a deterministic view of the universe where every moment in time is set in stone. On the other hand, particles in quantum mechanics have an inherently random nature and are seen from a probabilistic perspective. This suggests the universe has a random nature and is incompatible with Laplace's Demon.

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

Hello again everybody! This term has been busy as ever, as I'm sure it has for all of you reading at KES.

I don't have much new to report at this stage really, I'm working on a few interesting problems, and hoping to put a paper out sometime later this year. As there are no major updates, I thought I might tell you a little bit about a very important part of physics that I use in my everyday work, *Quantum Field Theory*.

You have probably encountered the term '*particle*' in a number of contexts. Generally, we think of a particle as a small unit of 'stuff'. A *fundamental* particle in particular, is the smallest possible unit of stuff. Electrons (we think) are fundamental particles, meaning you couldn't take a tiny knife and split an electron in half - it's the smallest amount of electron flavoured matter we can have.

One of the great revolutions of 20th century physics, was the revelation that the behaviour of tiny pieces of matter (like electrons, protons, neutrons, photons of light etc) behave very differently to bigger pieces of matter (like tennis balls, trousers, ants, coffee cups etc). The rules that describe this behaviour of tiny particles, we call *Quantum Mechanics*.

The other pillar of 20th century physics comes from Einstein. Einstein tells us (among other things!) that $E = mc^2$, with E for *energy*, m for *mass*, and c for the *speed of light*. One way of interpreting this equation, is that in certain circumstances, we are allowed to create mass by using up energy. This seems like an interesting conclusion. If you've been paying attention to your chemistry lessons, you will have heard that 'mass is conserved' (or more precisely, the number of protons, neutron and electrons are all fixed). This is essentially true for chemical reactions (which are not very energetic), but for much more violent reactions (like collisions of protons in the Large Hadron Collider at CERN), we cannot make such a statement.

Quantum Field Theory (or QFT) is the natural offspring of combining *Quantum Mechanics* (the rules for how tiny particles behave) with special relativity (Einstein's $E = mc^2$). With the knowledge that matter can spring, seemingly out of nowhere, our whole notion of 'what is a particle?' totally goes out the window.

The way QFT describes matter is a little different to the particle picture we're comfortable with. At the most fundamental level, we describe all matter and fundamental forces in the Universe via a *field*. An *Electron Field*, a *Photon Field*, six kinds of *Quark Fields*, and so on. Particles are no longer the most fundamental description of *stuff* in the Universe, fields are. What we know as particles are just excitations of the underlying fields, which fill the entire Universe.

You can picture a pot of water gently boiling on a stove. In this analogy the field is the smooth surface of the water, and the particles are the bubbles which cause the surface to excite and ripple.

There's a whole lot more that could be said here! In the meantime, you can check out this video.

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'.

(I'm often quite delayed in writing these up, so apologies in advance!)

How did the Universe start?
(Year 7)

With a BANG! (we think). Not the kind of bang you could hear though. The 'Big Bang' was the beginning of all space, matter, and energy in the Universe.

If we trace back the growth of our Universe today, we can see that around 13.8 billion years ago, all the stuff in the cosmos should have been crammed into the same point in space. In the 1960's Stephen Hawking proved mathematically that this was possible, through his work on *spacetime singularities*.

A spacetime singularity is a point in space and a moment in time, where the laws of physics as far as we know them break down entirely. The beginning of the Universe, and the centre of a black hole have this feature in common, both are spacetime singularities.

So what are the limits of what we can say about the start of the Universe? Well, beyond this spacetime singularity (the *Big Bang* itself) we cannot go much further.

We have a pretty good idea of what went on about 10^{-36} seconds after the big bang. Slightly less of an idea at 10^{-37} seconds after, and *far* less of an idea at 10^{-43} seconds after.

Studying the early Universe and the Big Bang is difficult for a number of reasons, but we are learning new things all the time!

Robert Clemenson

How are meteors made?
(Year 7)

A meteor is defined as any piece of rock that enters the Earth's atmosphere. Before entering the atmosphere, these rocks are called meteoroids. They normally enter the atmosphere at very high speed so, once they start colliding with molecules in the air, can become heated to very high temperatures due to friction. This causes them to glow which is why meteors sometimes appear as fire balls in the sky. Most meteors entirely burn up during this but some make it to the ground. In this case, they are called meteorites.

Meteoroids can have a few different origins but most have been around since the formation of the solar system. Currently, it is thought that the solar system formed from the collapse of part cloud of matter. The cloud contained so much mass that gravity pulled parts of it together. As these regions became denser, most of the matter came together to form the Sun whilst other fragments formed a surrounding, rotating disk. Over millions of years, these fragments collided and accreted to form larger bodies such as planets. However, many smaller fragments remain and these form the asteroids and meteoroids that exist throughout our solar system today.

Paul Jarvis

Did Isaac Newton actually have an apple fall on his head?
(Year 7)

In all honesty, no. However, there a number of individuals at the time have written accounts that Issac Newton told them he first thoughts on gravity occurred to him when he saw an apple fall from a tree. Whether this is really the case, or he just used the falling of an apple as an example to think about and explain his ideas is still debatable. Nonetheless, there is a tree at Woolsthorpe Manor in Lincolnshire, where Newton lived, which apparently is "the tree" from which the apple fell.

Paul Jarvis

What are black holes? What do they do? (Year 7)

A black hole is what happens when gravity wins. We all know roughly how gravity works, it pulls us down towards the Earth, it pulls the Earth into orbit around the Sun, and the Sun into orbit around the centre of the galaxy. Gravity wants to cram matter together as much as is possible.

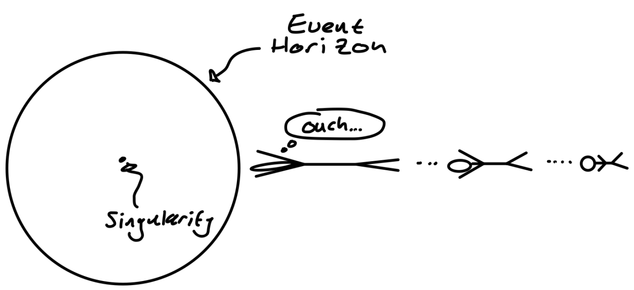
However, usually gravity is not the only force present. Fortunately for us, our feet are made of atoms, and these atoms have negatively charged electrons whizzing around inside. The negative electrons in our feet repel the negative electrons in the ground, which allows gravity to be overcome, stopping us from all being crumpled together at the centre of the Earth. This is possible because the repulsive force between out feet and the ground is stronger than the force of gravity trying to squash us down.

But what happens when gravity is the strongest force? This is only ever the case in some of the largest stars in the Universe (over ~60 times the mass of our sun). When all other options have been exhausted, and all nuclear fuel burned off, a star will have no choice but to collapse inwards due to gravity. When this collapse is unhalted, the collapse continues indefinitely. With all the mass of the star compressed to a single point in space with infinite density, the *Singularity* of the black hole.

Surrounding the singularity is the *Event Horizon*, the dark boundary between the Universe outside the black hole, and the interior from which there is no escape.

Black holes are truly bizarre objects. They bend space, slow down time, and play a large role in the formation of galaxies. I look forward to telling you more about them soon!

Robert Clemenson



Do you die if you fall into a black hole? (Year 7)

In one sense **yes**, in the other sense **no**. Is that clear? Ok good. Just kidding...

The weird thing is, it's all really a matter of perspective. Let's consider a very very big black hole (say, over 1 million times the mass of our sun - this would in fact be called a *supermassive black hole*). The reason I want to think about big black holes, is that these are actually a lot more gentle to fall into. It's the small scrappy black holes that will rip you apart by *spaghettification* (the technical term for having your body pulled into a long length of human spaghetti by a hungry black hole).

So for a supermassive black hole, we don't have to worry about being spaghettified at the even horizon. Now let's suppose you and I are sat inside a spaceship some distance from the black hole, and you decide to dive head first into the beast (that seems a bit silly, why would you do that??). What happens next is now totally dependant on who's making the observation. So let's discuss the two cases separately.

From my perspective: I see you plummet towards the horizon of the black hole, but as you get closer and closer to passing through the horizon, you begin to slow down (as if in slow motion). You keep getting slower and slower, never quite passing through the horizon of the black hole. All the while, you become flatter and flatter, becoming smeared across the horizon. But still, I never see you fall through. To me, time appears to have frozen for you - so from my perspective you never even fell into the black hole!

From your perspective: You feel yourself falling towards the horizon of the black hole, and accelerating (not slowing down as I saw happen). You pass through the horizon as if it wasn't even though, and you look up back towards my spaceship as you do, and see the Universe jolt up in speed - supernovae, galaxies colliding, the entire Universe may pass you by in an instant. The rest of the tale is not as pleasant.. As you fall towards to singularity of the black hole, tidal forces on your body increase, and you are ripped apart. Death by black hole.

Robert Clemenson

What makes a planet habitable?
(Year 7)

Ultimately, many things need to be "just right" for the planet to be habitable. This has led to an idea called the Goldilocks Principle. In the story of Goldilocks and the Three Bears, Goldilocks tries three bowls of porridge and prefers the one which is neither too hot or too cold but "just right". This can be extended to determining the conditions for life, particularly in regards to the presence of liquid water. For example, if the Earth was nearer the Sun, it would receive more radiation from the Sun, possibly rising the surface temperature and keeping it too hot for liquid water to exist (it would be vapour instead). Conversely, if the Earth was further away, it would receive less radiation, leading to a colder surface where water would freeze. Without liquid water, life probably, couldn't exist and this has given rise to the idea of a habitable zone around the Sun where liquid water could exist. Of course, water isn't the only consideration, but its possibly the most important.

Paul Jarvis

Revision Tips
(Year 10 & 12)

Let me first entirely plagiarise 'Tim Souths 1 step guarantee to education success' from the Summer 2017 issue of this newsletter: **ALWAYS DO PAST PAPERS**. You know the thing you're going to have to do in the end is an exam of a particular format, so the very best preparation you can do is to get lots of practice doing questions from that particular format.

Past papers alone aren't much use though. They're great for identifying what it is you don't know, but if you then don't go away and learn the things you got wrong, you're always going to make the same mistakes!

When I was revising, I would write in red on the front of practice exams all the topics I'd made mistakes on. I'd then go away, spend a few hours reading about, making notes on, and practicing similar questions from the topic, and then come back to retry the questions from the paper. After all of this, you should have a model set of solutions for the practice paper, and some good notes on the topics you got wrong!

Robert Clemenson