Physics Department Newsletter

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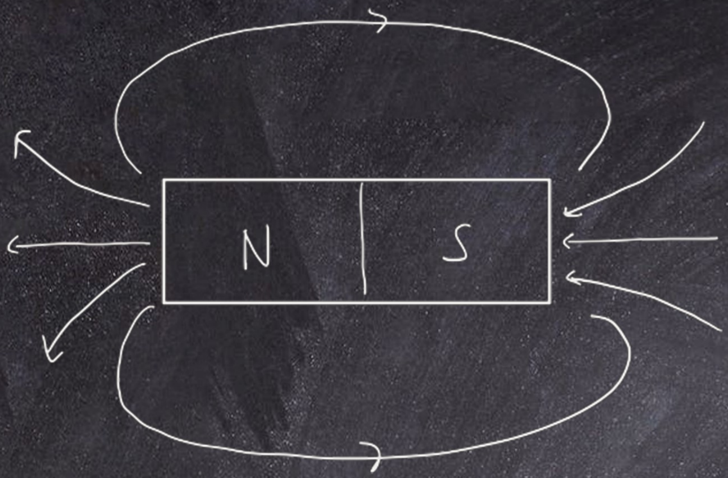
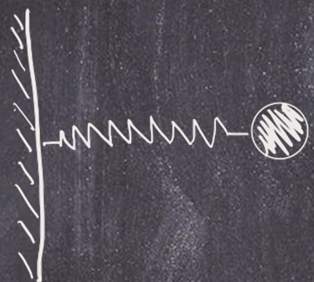


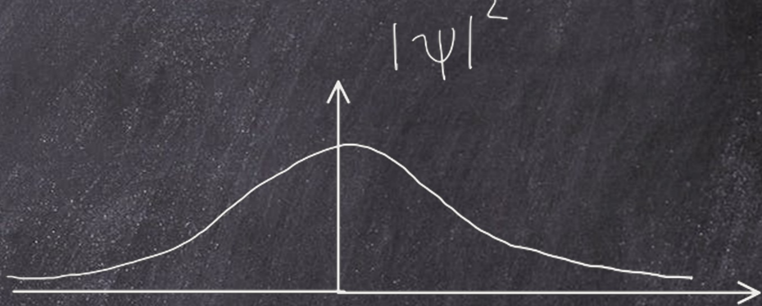
$$\nabla \cdot \vec{E} = \frac{1}{\varepsilon_0} \rho$$

$$\nabla \cdot \vec{B} = 0$$

$$\nabla \times \vec{E} = -\frac{\partial}{\partial t} \vec{B}$$

$$\nabla \times \vec{B} = \mu_0 \vec{J} + \mu_0 \varepsilon_0 \frac{\partial}{\partial t} \vec{E}$$





$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{x}}\right) = \frac{\partial L}{\partial x}$$

$$m\ddot{x} = -kx$$

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HERIOT WATT UNIVERSITY
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A sort of 'goodbye' and a huge thank you

Dr. P. Dalgarno, Deputy Director of Learning and Teaching

As I write this I have just this very last hour signed off the final piece of paperwork I have responsibility for as Head of Heriot-Watt Physics teaching (Senior Program Director of Studies - SPD). My tenure in the role officially ended on 1st June, but I continued to carry out key responsibilities in order to run the award and progression boards at the end of this academic year. With those being wrapped up this this week, the SPD reigns are now firmly handed over to the brilliant Dr. Graeme Whyte.

For those that do not know – I am not physically going anywhere, I remain part of the physics teaching group and will continue to teach everything I did before – I just have new responsibilities as the new Deputy Director of Learning and teaching (DDLT) for the school.

It is a strange feeling. The SPD role had its pressures and challenges so there is some degree of relief, but challenges are good, and I am very much looking forward to the new ones as DDLT. That said, being SPD has also been the single greatest period of my career and I will miss much of it greatly. I have learnt so much, and the experience has been amazing for me as an individual. By far the best thing was working alongside colleagues and students to deliver the best we can for physics at Heriot–Watt. Finishing each year by signing off student degree awards and progression decisions was also awesome – it makes everything worthwhile to see students graduate to better things or progress to their next year of study. The massive office was pretty sweet too.

Of course, my time as SPD just happened to overlap one of the biggest challenges in the history of higher education - which was fun. In my relatively short 31-month tenure, 15 of those months was under Covid-19 and the restrictions imposed. I blame Dr. Bill Macpherson (my SPD predecessor) completely, because when he told me what being an SPD was all about, he utterly failed to mention the risk of a global pandemic and ensuring disruption. It was incredibly short-sighted of him.

When the pandemic started I confess, it was all chaos and fear, with a completely unknown vision of how things will all work out. But almost a year and a half on I have been amazed at the resilience, innovation and resolve of both the students and staff of physics at Heriot-Watt. This of course is not how we want to teach or learn – it is not the university experience anyone wants but I proudly believe we all did the best we can under unimaginable difficulties.

I am delighted Dr. Graeme Whyte agreed to step into the SPD role. Already (and only a few formal weeks in) he has excelled, and I have no doubt at all that he will be fantastic for physics. I genuinely look forward to working alongside him as part of the physics teaching group and as DDLT in the future.

So, I want to sign off as SPD by thanking everyone in physics for being part of this amazing experience: the staff, students, and any of our former students. Being SPD is something that I will forever be grateful for and very proud of. It really has been the greatest honour.

Fabios's Corner – The magnetic monopole: if you find it, don't destroy it!

Dr. Fabio Biancalana – Biancalana Group

In this Issue I would like to tell you about one of the strangest and most fascinating facts about a mysterious particle, called the Magnetic Monopole.

We all know electrons: they carry electricity in our houses,and they are all around us – every atom has a number of electrons orbiting around its nucleus – electrons are one of the most common constituents of matter. Electrons carry an "electric charge". We all know that there are two types of electric charge, positive and negative, and they can exist independently – for instance, the electron has a negative electric charge, while the proton has a positive electric charge. This nomenclature is of course completely arbitrary: we could have called it type-A charge and type-B charge, or whatever else, these are just names that scientists give to things to classify them. The important thing is that there are two types of electric charge, no more and no less.

Magnets are very different – they also have two "charges", which we call "North pole" and "South pole" (again, names are completely arbitrary) – but they cannot exist independently, in the sense that we cannot have a magnet that has only the North pole charge, or only the South pole charge; they must always coexist together. If you try to divide a magnet into two parts, each part will still have a North and a South pole – physicist say the "monopoles" cannot exist.

Most (if not all) fundamental theories of physics, however, say something very different: they all predict the existence of a special elementary particle, called the Magnetic Monopole, which carries only one of the magnetic charges i.e., there should be particles which have only a North pole, and particles that have only a South pole. Physicists have spent decades searching for evidence of the existence of such particles and failed spectacularly – since no Magnetic monopoles have ever been found in experiments despite the fact that, if it exists, it should be very visible in experiments.

Where are the Magnetic monopoles? Do they really exist? One of the most fascinating theories of cosmology (supported by lots of experimental measurements) called Inflation, says that the ultra-rapid expansion of the Universe immediately after the Big Bang was so rapid, that the Magnetic monopoles have diluted so much that their density is on average "one per Hubble volume", i.e., one per observable Universe. In other words, in our observable Universe there should be approximately one Magnetic monopole on average.

In 1931 the British physicist Paul Dirac discovered with beautifully simple arguments that if just a single Magnetic monopole exists, then it follows that all the electric charges are "quantized", which means that all electric charges would be identical and will show up in indestructible units – exactly what we observe in Nature. For instance, the electric charges of the electron and the proton have opposite signs, but exactly identical magnitude – and that magnitude is the same for all charged particles in the Universe – something that we usually take for granted without knowing exactly why.

More precisely, Dirac discovered that the elementary electric (q_e) and magnetic (q_m) charges of particles are related by the formula

$$\frac{q_e \cdot q_m}{2\pi\varepsilon_0 \hbar c^2} = n,$$

where ε_0 is the permittivity of vacuum, c is the speed of light and $\hbar$ is Planck's constant of quantum mechanics. The integer n is arbitrary. The above formula comes from quantum mechanics, and it makes the equation of electromagnetism beautifully symmetric, since electric and magnetic fields are treated on equal footing.

If magnetic monopoles exist then they must interact with matter in a *very* strong way. Electromagnetism is quite a "weak" force, since the probability that an electrically charged elementary particle interacts with light is quite small and is regulated by the so-called fine structure constant: $\alpha_e \approx 1/137$, which is a number much smaller than 1. However, the probability that a magnetic charge interacts with matter is proportional to the *inverse* of that number: $\alpha_m \approx 137$, and so magnetic monopoles should be in principle *very* visible in experiments. But to this day, none have been found.

This makes us wonder: where is the Magnetic Monopole in our observable Universe? Is there really only one Magnetic monopole in our Universe, or is there more than one? One thing is sure – if you find it, don't destroy it! Because if you do, all the electric charges of the Universe could instantly lose their "quantization", and a huge, spectacular electromagnetic destabilization of the entire observable Universe could take place. Not something we want to do!

Using conditional probability to obtain a counterintuitive result

Martin Damyanov, 4th Year MPhys Mathematical Physics

A few months ago, I realized that I lack some important mathematical knowledge in the field of probability and statistics. Yet, I noticed that such knowledge is not only expected of me for my career in physics but is essential for anyone who wants to orient themselves properly in the modern data-driven world. After all, we all know how easy it is to lie and manipulate using statistics. With that in mind, I decided to undertake the journey and educate myself on this subject. My aim here is to share some of the interesting and counterintuitive results that I encountered in the hope that you will also find them fascinating. With that being said, let's jump to today's topic - the concept of conditional probability!

Conditional Probability

The statement that the probability of an event A is some number $x \in [0,1]$ can be interpreted in different ways. It can be viewed as the representation of the frequency of the occurrence of the desirable outcome over a large number of repetitions of an experiment. This is known as the frequentist interpretation. There is also the Bayesian interpretation of probability, which is that it represents a degree of belief we have about the event A. For example, if we are tossing a coin that we believe is fair then we write $P(heads) = P(tails) = 0.5$.

In everyday life we are constantly updating our beliefs. Whether by performing an experiment in a lab and observing something unexpected or, by finding out that you have just missed the bus and you are unlikely to be on time for an appointment. We want to have the ability to incorporate this additional information and make better judgements for the future. This is where conditional probability comes into play. Mathematically, the conditional probability of A given B is defined as:

$$P(A|B) = P(A \cap B)/P(B)$$

That is, the updated probability of event A now that we have observed event B happening, whereas $P(A)$ is our prior notion of the probability of A.

It is a simple mathematical definition, but it quickly leads to some very counterintuitive results. Here is an example [1]:

A family has two children. Find:

A) The probability that both children are girls given that they have at least one girl.

B) The probability that both children are girls given that they have at least one girl born in winter.

Assume that both genders are equally likely, that the genders of the two children are independent, that gender is independent of the season and that all seasons are equally likely.

Solution:

A) Applying the definition of conditional probability:

$$P(A|B) = \frac{P(A \cap B)}{P(B)}$$

We have that,

$$P(A|B) = P(both\ girls|at\ least\ one\ girl)$$

$$P(A \cap B) = P(both\ girls \cap at\ least\ one\ girl) = \frac{1}{4}$$

$$P(B) = P(at\ least\ one\ girl) = \frac{3}{4}$$

$$\therefore\ P(A|B) = \frac{1/4}{3/4} = \frac{1}{3}$$

B) Applying the definition again, we have

$$P(A|B) = P(both\ girls\ |at\ least\ one\ winter\ girl)$$

$$P(A \cap B) = P(both\ girls \cap at\ least\ one\ winter\ girl)$$

$$P(B) = P(at\ least\ one\ winter\ girl)$$

The probability of a child being a winter born girl is $1/8$ and therefore, the probability of a child not being a winter born girl is $7/8$. The probability that both children are not winter born girls is then $(7/8)^2$. Hence,

$$P(at\ least\ one\ winter\ girl) = 1 - P(no\ winter\ girls)$$

$$= 1 - \left(\frac{7}{8}\right)^2 = \frac{15}{64}$$

We also have that the probability that a child is not born in winter is $3/4$ which gives the probability that both children are not born in winter is $(3/4)^2$.

We can now rewrite our equation making note that, $P(both\ girls \cap at\ least\ one\ winter\ girl) \equiv P(both\ girls \cap at\ least\ one\ winter\ child)$.

Therefore,

$$P(both\ girls \cap at\ least\ one\ winter\ child)$$

$$= P(both\ girls)(1 - P(no\ winter\ children))$$

$$= \frac{1}{4}\left(1 - \left(\frac{3}{4}\right)^2\right) = \frac{7}{64}$$

Combining all of this gives:

$$P(both\ girls|at\ least\ one\ winter\ girl)$$

$$= \frac{7/64}{15/64} = \frac{7}{15}$$

How is it possible that the season of birth changes the probability?! Why does it even matter? Knowing the month is an extra bit of information and we have to include it in the final analysis, even though it might seem irrelevant. The devil is always in the details!

The example problem for this article was taken from the book “Introduction to Probability” by Joseph K. Blitzstein and Jessica Hwang. There you can find further information regarding the example problem and intuitive reasoning for the answer. In my opinion it is a great book and I highly recommend using it as an introduction to the field of probability and statistics.

[1] Blitzstein, J. K. and Hwang, J. (2019) Introduction to probability. Second edition.

Shared Experiences – Life After Graduation

Sean Keenan, 5th Year MPhys Physics

In this series, we have Thomas Rowe and Danny Hunter, both of whom have taken very interesting and different paths in their studies. Danny has gone down the PhD route – working with Dr. Richard McCracken on low-cost OPOs and, like myself, is a mature student – showing that age isn’t a limit on pursuing your passion!

What inspired you to get into Physics?

My kids. They have endless questions, and each answer prompts the next “But, Why?”! I am not a “Just because!” kind of person so their line of questioning led me down many a rabbit hole on Google. Eventually, after a particular line of questioning took my son and I all the way back to the big bang, I decided that I wanted to know more. I went to the Open University, then to college and finally to Uni.

What is your current role and what steps did you take to get there?

I'm a post graduate research student developing new ways to build low-cost optical parametric oscillators (OPOs) for multiphoton microscopy. I first started by applying for the opportunity to do a summer project after 3rd year in the same field of study. The project was 8 weeks long and allowed me a glimpse into what experimental research would be like. I really, really enjoyed it and it ignited a passion for all things lasers that I turned into an 'A' in the 4th year Laser Physics course. The PhD opportunity was advertised via email and the project proposal read like a 3-year-long version of my best summer ever, so I applied.

Danny Hunter is currently a 1st year PhD student working in the McCracken Lab.

What is your favourite part of your current work?

Light is definitely the most interesting thing I've studied as a physics student.

We take it for granted as it's everywhere and everything we see, but there is so much more to it. Being able to manipulate the smallest, fastest and most abundant of our physical phenomena is fascinating to me. Everything from making rainbows to bending it round corners still amazes me every day in the lab.

How has your degree helped you in your current role / what has been the most useful aspect of your degree?

The lab sessions in the first three years of my degree have proven invaluable. Lots of experience at lab book writing in a way that you can still understand in a week or a months' time is a priceless skill. The final years project was a good crash course on self-motivated research too.

Has your degree in physics helped you in any way that isn't explicitly linked to science?

Gaining my degree aged 39 earned me self-confidence and self-belief that I'd have otherwise not had. The process of getting to the graduation stage was as much about learning the subject matter as it was about self-discovery and growth. Being able to bring those attributes into the lab with me now has helped me hit the floor running.

What have been the biggest challenges in your career so far?

Being diagnosed with dyspraxia at 32 has been a big challenge. Finding ways to work with my condition and keep to the time frames of deadlines and semester dates hasn't always been easy. Learning how I learned best was one of the biggest challenges to overcome and I had to find out fast. Unfortunately, not fast enough for my first 1st year. The repeat year was more successful.

Is there anything you dislike about physics / disliked in your degree?

Quantum Mechanics!

I got into physics because I liked the idea that everything had an exact answer – quantum mechanics seems to go against that.

Plus, it's weird and hard!

If there was one piece of advice you wish someone gave you in 1st year – what would it be?

There is so much I wish I could tell 1st year me!

Firstly, I'd say, "You absolutely deserve to be here!" and I'd get them to google impostor syndrome. Then my advice would be keep giving it everything, even while you're passing, but when you start to fail, give it the rest as well. Lastly, I'd say that anxiety is a liar and if some random in the street said those same things to you, you'd tell them where to go.

Thomas on the other hand has gone down the medical physics route and is a Trainee Medical Physicist at NHS Tayside:

What inspired you to get into Physics?

Physics was always one of my strong areas throughout high school and something I had a natural interest in. When it came to applying to university, it seemed like the right fit. I've always been curious about understanding how things work at a deeper level so, studying Physics seemed like a good choice.

What is your current role and what steps did you take to get there?

I am currently a Trainee Medical Physicist at NHS Tayside. As part of my job, I have spent the last year studying MSc Medical Physics and I am currently completing my research project at Ninewells, Dundee.

Thomas is a trainee medical physicist at NHS Tayside.

At Heriot-Watt, my research project was relevant to Medical Physics - from there I took an interest in a career in Medical Physics. I went to a few open days and reached out to several Medical Physicists to get a better understanding of the role and what is involved. Having the chance to experience what other careers are available from a Physics degree helped me to understand what area I wanted to work in after graduating.

What is your favourite part of your current work / what do you find most interesting about physics?

My favourite part of my job is the opportunity to get involved in a variety of different areas and get to understand how Physics is applicable to healthcare. I am currently completing my MSc research project at Ninewells in MRI, and in the following year I will get to work in Nuclear Medicine, Radiotherapy and Diagnostic Radiology & Radiation Protection. Getting involved in different Medical Physics departments feels like a fantastic chance to meet other professionals and get a feel for what area I wish to specialise in.

How has your degree helped you in your current role / what has been the most useful aspect of your degree?

The biggest advantage I took from my degree was from my research project in 4th year. Having a wide range of projects to choose from allowed me to think about what areas of Physics I'd like to be involved with in the future. Being involved in the research project allowed me to understand how physics can be applied in a medical setting and gave me the push to research what careers were available, whilst also gaining some experience in a relevant area.

Has your degree in physics helped you in any way that isn't explicitly linked to science?

Being at university has helped me grow my confidence and social skills – initially you are surrounded by a lot of people with similar interests and it gives you a chance to meet new people and expand your network. Whether it was being partnered up with someone new in lab work or chatting to course mates between lectures there was always room to grow your social skills.

What have been the biggest challenges in your degree / career so far?

The biggest challenge in my degree/career (as of now) would most likely be trying to complete the MSc in Medical Physics throughout Covid and (several) lockdowns. Not getting to meet other course mates face to face and having to learn all the material from lectures at home was a new and challenging experience in comparison to the normal face to face learning and getting to know your course mates.

Is there anything you dislike about physics / disliked in your degree?

Throughout my degree, I never particularly enjoyed experimental labs. I much preferred the theory-based courses however, when it came to my research project in 4th year I thoroughly enjoyed getting stuck in and being involved in new and relevant work.

If there was one piece of advice you wish someone gave you in 1st year – what would it be?

Get involved in as much as you possibly can! There are always opportunities to take part in activities (whether it is university related or not) which can strengthen your CV in the future and help you understand where you want your career to take you.

List of Latest Research Output

Modelling dispersion compensation in a cascaded-fiber-feedback optical parametric oscillator.
Allan,E.; Ballantine,C.; Robarts, S.C.; Bajek, D.; & McCracken, R.A.
In: Optics, 2, 96–102.
https://doi.org/10.3390/opt2020010

Feasibility of quantum key distribution from high altitude platforms.
Chu, Yi ; Donaldson, Ross; Kumar, Rupesh; Grace, David .
In: Quantum Science and Technology, Vol. 6, No. 3, 035009, 07.2021.

Monolayer as an Ideal Test Bed for the Universality Classes of 2D Magnetism.
Dupont, M.; Kvashnin, Y. O.; Shiranzaei, M.; Fransson, J.; Laflorencie, N.; Kantian, A.
In: Physical Review Letters, Vol. 127, No. 3, 037204, 16.07.2021.

Ultrafast laser ablation of a multicore polymer optical fiber for multipoint light emission.
Kuzhikkattu Chandrasekharan, Harikumar; McShane, Eunan; Dhaliwal, Kevin; Thomson, Robert R.; Tanner, Michael G.
In: Optics Express, Vol. 29, No. 13, 21.06.2021, p. 20765-20775.

Custom-Technology Single-Photon Avalanche Diode Linear Detector Array for Underwater Depth Imaging.
Maccarone, Aurora; Acconcia, Giulia; Steinlehner, Ulrich; Labanca, Ivan; Newborough, Darryl; Rech, Ivan; Buller, Gerald Stuart.
In: Sensors, Vol. 21, No. 14, 4850, 16.07.2021.

Backscattering in nonlinear microring resonators via a Gaussian treatment of coupled cavity modes.
McCutcheon, Will.
In: APL Photonics, Vol. 6, No. 6, 066103, 06.2021.

Generation of half-integer harmonics and efficient THz-to-visible frequency conversion in strained graphene.
Ornigotti, Marco; Ornigotti, Luca; Biancalana, Fabio.
In: APL Photonics, Vol. 6, No. 6, 060801, 06.2021.

Experimental quantum conference key agreement.
Proietti, Massimiliano; Ho, Joseph; Grasselli, Federico; Barrow, Peter; Malik, Mehul; Fedrizzi, Alessandro.
In: Science Advances, Vol. 7, No. 23, eabe0395, 02.06.2021.

Room-temperature continuous-wave vertical-cavity surface-emitting lasers based on 2D layered organic-inorganic hybrid perovskites.
Zhang, Hongbo; Hu, Yuzhong; Wen, Wen; Du, Bowen; Wu, Lishu; Chen, Yu; Feng, Shun; Zou, Chenji; Shang, Jingzhi; Fan, Hong Jin; Yu, Ting.
In: APL Materials, Vol. 9, No. 7, 071106, 07.2021.

Astrophotonics : Introduction to the feature issue.
Dinkelaker, Aline N.; Rahman, Aashia; Bland-Hawthorn, Joss; Cantalloube, Faustine; Ellis, Simon; Feautrier, Philippe; Ireland, Michael; Labadie, Lucas; Thomson, Robert R.
In: Applied Optics, Vol. 60, No. 19, 01.07.2021, p. AP1-AP6.

Astrophotonics : introduction to the feature issue.
Dinkelaker, Aline N.; Rahman, Aashia; Bland-Hawthorn, Joss; Cantalloube, Faustine; Ellis, Simon; Feautrier, Philippe; Ireland, Michael; Labadie, Lucas; Thomson, Robert R.
In: Journal of the Optical Society of America B: Optical Physics, Vol. 38, No. 7, 01.07.2021, p. AP1-AP6.

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