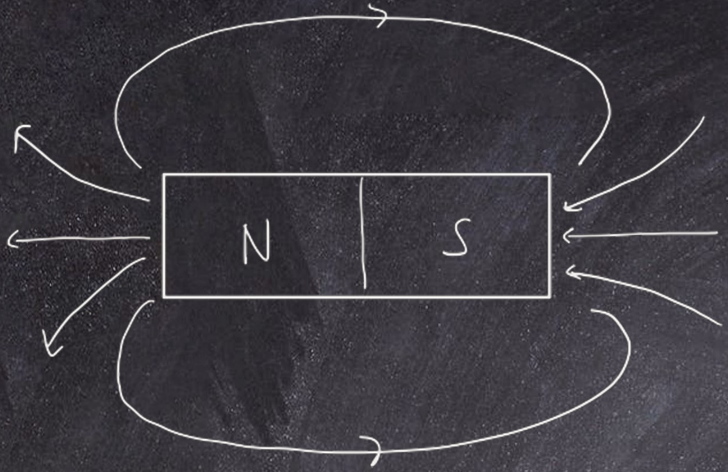
HERIOT WATT UNIVERSITY

Physics Department Newsletter

Volume 2, Issue 01

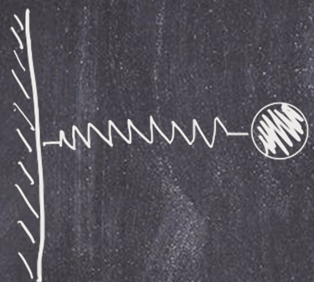


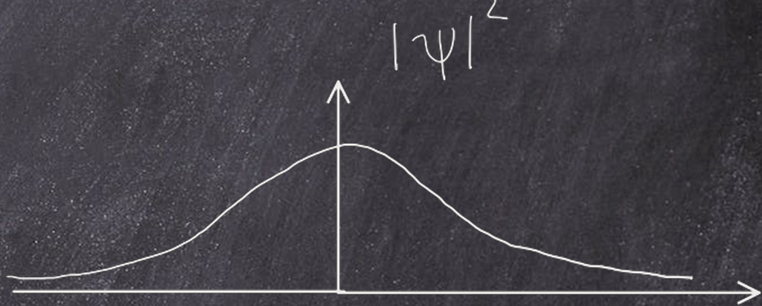
$$\nabla \cdot \vec{E} = \frac{1}{\varepsilon_0} \rho$$

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

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

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





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

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

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HERIOT WATT UNIVERSITY
Physics Newsletter
Vol. 2 Issue 01 October 2021

Yet more change – a new year a new Head of Physics Teaching

Dr. Graeme Whyte, Senior Programme Director

It is a wonderful pleasure and honour to be taking over the role of head of Physics teaching – or Senior Programme Director (SPD) as it's known – and a very warm welcome to all new and continuing students within Physics. Paul Dalgarno as outgoing SPD has done an amazing job running and striving to improve our Physics teaching and student experience, not to mention the Herculean task of leading Physics through all the mammoth changes, challenges and adaptations brought by the pandemic, and so hands over a well-running physics department in a good position to tackle the challenges ahead.

I'm extremely grateful that Paul and Dr Bill McPherson (the SPD before) are still here at Heriot Watt Physics and highly active and passionate about making Heriot Watt Physics the best place to study (and for answering my never-ending string of questions – there's no handbook to being SPD and 1,001 things to learn … good thing I'm at university!) I'm also honoured to have such a wonderful group of talented and skilled academics who make up the Physics teaching group. Every one of them has all pulled out all the stops to provide the best experience possible in these challenging times. In any discussion about changes, it is always enheartening to hear that the first consideration is the student experience.

It feels as if the last year and half has been a whirlwind of change and uncertainty, with huge efforts required to constantly adapt and try to prosper under difficult circumstances. Unfortunately, despite having the best intentions, we have not always got things right. I am, however, overwhelmed by the support and pragmatism shown by students towards staff to help improve things. I hope that we can build on the collective spirit to further enhance Physics at Heriot Watt as a community as well as a leading university department. Going forward, hopefully the worst is now behind us and we can concentrate on incorporating the best elements of our previous teaching and our pandemic teaching to build a better degree program and provide the best physics degree experience we can.

As restrictions ease and more students and staff are on campus, it is important to build back the connections and social aspects of university life. While Physicists are not renowned for their gregarious social skills, the connections and networks built up at university can provide a life-long personal and professional support system which can come back to benefit you in very unexpected and unsought ways in the short term and in the far future. Heriot-Watt Physics has benefitted hugely from having highly active and organized student-led initiatives, from the Physics Society and their wonderful events, the Watts Up space programme and their astronomical goals, to this excellent newsletter, but these initiatives, although supported by staff and the department, require student engagement and participation to succeed. Recovering from the pandemic allows us an opportunity to reshape things in the way that you want them to be so, please get involved and be a part of the positive change.

Testing for a rare disease

Martin Damyanov, 4th Year MPhys Mathematical Physics

In this month's issue we will look at another interesting and counterintuitive probability problem. To be able to solve it, we will need two important results from probability theory – Bayes' rule and the law of total probability.

Bayes' Rule

Bayes' rule is an extremely important result that relates the conditional probabilities $P(A|B)$ and $P(B|A)$, namely:

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

Where $P(A|B)$ is the conditional probability of A given B. For example, say there are two bags, numbered 1 and 2, each containing blue and red balls. We pick one ball at random. Let A be the event that the ball we picked is red and B – the event that we chose bag 2. We will have that $P(A)$ is the probability that we picked a red ball given we chose the bag randomly, whereas $P(A|B)$ is the probability we got the red ball given we decided to pick from bag 2.

Law of Total Probability

The law of total probability is an important theorem which relates unconditional to conditional probability. It states that, if $B_1, B_2, \dots, B_n$ is the partition of the sample space S (that is, the B_i are disjoint events with union S) where $P(B_i) > 0$, then

$$P(A) = \sum_{i=1}^{n} P(A|B_i)P(B_i)$$

Thinking back to the bag with balls example, this simply states that the probability of picking a red ball is the probability of picking a red ball given you chose a specific bag times the probability of choosing that bag, summed over all bag choices.

Equipped with these two results, we are now able to tackle the following problem.

Testing for a rare disease [1]

We have a patient named Fred who we want to test for a rare disease that afflicts only 1% of the population. Let D be the event that Fred has the disease and T be the event that he tests positive. The test we have is "95% accurate". In this problem that is assumed to mean that $P(T|D) = 0.95$ and $P(T^c|D^c) = 0.95$. The quantity $P(T|D)$ is known as the *sensitivity*, or *true positive rate*, while $P(T^c|D^c) = 0.95$ is the *specificity* or *true negative rate*. Here T^c is event that Fred tests negative, and D^c the event that he does not have the disease.

Of course, we have that poor Fred tests positive for the disease! However, we want to know the probability that he *actually* has the disease given that he tested positive.

Solution:

Bayes theorem gives us

$$P(D|T) = \frac{P(T|D)P(D)}{P(T)}$$

We can use the law of total probability to re-write the denominator as

$$P(T) = P(T|D)P(D) + P(T|D^c)P(D^c)$$

$$= P(T|D)P(D) + (1 - P(T^c|D^c)P(D^c)$$

Translating this into Bayes formula gives

$$P(D|T) = \frac{P(T|D)P(D)}{P(T|D)P(D) + (1 - P(T^c|D^c)P(D^c)}$$

$$= \frac{0.95 \times 0.01}{0.95 \times 0.01 + 0.05 \times 0.99}$$

$$\approx 0.16$$

Surprisingly there is only a 16% chance that Fred has the disease (lucky him!) given that he tested positive. The key is to understand that there are two factors at play here – the evidence from the test and the prior information about the prevalence of the disease. Although the test is quite accurate, the disease is quite rare.

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

Radioctive felines – determining the half-life of a cat

Dave Muir, 4th Year BSc Mathematical Physics

Abstract:

I was given the opportunity to analyse a radioactive cat and monitor the decay. Overall, despite the difficulties of working with what can only be described as an obtuse creature, I actually got some fairly reasonable results and calculated that the half-life of a radioactive cat to be 4.3 days +/-0.7 days.

Aim:

A cute but rather poorly cat... Perfect for experimenting!

My girlfriend's cat had a problem with its thyroid – the treatment required that the cat would be given an injection of the radioactive isotope Iodine 131. I therefore decided that this would give me the opportunity to monitor how radioactivity decays within a living organism, as well as the opportunity to design and run an experiment to analyse this. I therefore emailed Dr Paul Dalgarno and requested to borrow a Geiger counter*, which he was kind enough to provide. Initially, I had thought to try and run an experiment to see if I could calculate the half-life of I131 by monitoring the decay in the cat however, the problem with this is that while the isotope decays the cat's radioactivity will also decrease due to the cat laying its daily "cat egg" along with other excretions. I could potentially monitor the decay of the isotope by taking one of the cat's "eggs", putting it in a Tupperware container and putting it in the freezer – which could then be monitored daily. However, I decided that keeping a radioactive "cat egg" in a freezer for the next month (next to my ice cream and frozen peas) would not be desirable. Therefore, I decided that the experiment would be to look at how the radioactivity decayed in the cat as a whole and that I would look to calculate the half-life of a radioactive cat due to its metabolism and the decay of the I131 isotope. I would therefore monitor the radioactivity levels daily and analyse accordingly.

**Although the equipment used is officially called a scintillation meter it will be referred to as a Geiger counter throughout the* *report simply because it sounds cooler and is easier to type and spell.*

Method:

I would attempt to record the counts per second daily over a three-week period, before analysing the results accordingly. This was easiest when the cat was having his early morning nap.

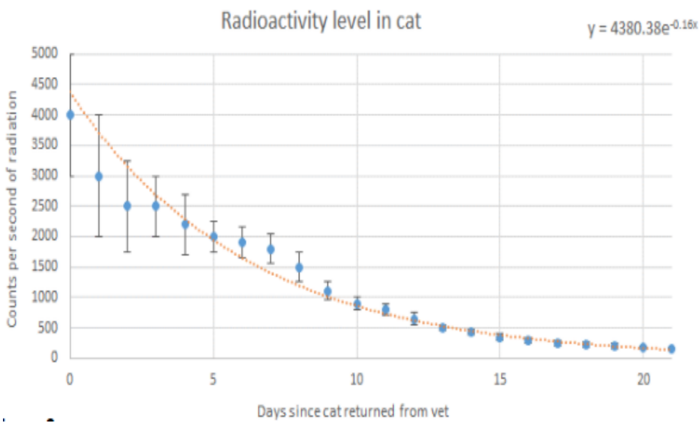
Science bit:

I131 decays by giving off a beta particle and changing into a Xeon particle as follows:

$$^{131}_{53}I \rightarrow ^{131}_{54}Xe + ^{0}_{-1}e$$

Results:

Overall, the results were moderately successful despite the subject's best efforts to derail my experiment by being unco-operative when it came to take his daily reading. A full summary of the results can be seen in the figure below:



Decay in radiation measured from the cat in days since his return from the vet.

From this I was then able to get an equation that models the rate of decay of radioactivity in a cat as a result of both the radioactive decay of the I131 isotope and the cat's natural metabolic rate and from that I could calculate the cat's half-life:

$$Decay\ rate\ of\ radioactive\ cat{:}\ \gamma = 4380\ e^{-0.16x}$$

$$Cat\ Half\ Life = 4.3\ days \pm 0.7\ days$$

Discussion:

Initially, after I familiarised myself with the Geiger counter, I noted that it was straight forward to use and had a log scale going from 0 to 2000 counts per second (CPS). I assumed that this would be the sort of low levels that would be expected to see given that this was a piece of equipment that would be used in a university lab and not in the core of Fukishima. So, you can imagine my surprise when the cat came back from the vet and I went to take my first reading and, before even getting within about 1m of the cat the dial had already gone off the scale. Upon reviewing some videos of similar meters being used at the fairground at Pripyat it was noted that even the background radiation on the outskirts of Chernobyl seemed to be reading in the region of 500-1000 cps. Thankfully, from my physics lectures this year I was reassured that the cat would not be gaining any superpowers as this would cause me to lose sleep given the cats general disdain for me; I did check though to see if the cat was glowing in the dark and pleasingly it wasn't.

The high-level readings from 'Chernobyl cat' did cause me problems in the beginning, seeing as the readings were off the scale. I therefore tried to work around this by measuring the distance where the Geiger counter read 500 cps to the cat and the distance to the cat where the Geiger counter read 1000cps. I could then use the inverse square law of radiation dispersion from a point to extrapolate the level at the source which was approximately 4000 cps on day 0. This did mean that there were large errors in the initial readings. It wasn't until the levels of radiation in the cat got to the region of 100-2000 cps that more accurate readings could be made with smaller error ranges. After the experiment based on the more accurate readings taken later on it was calculated that the initial value may have been around 4400 cps. A second major source of error was caused by the difficulty to measure the cat. Even a 1cm movement from the thyroid around the throat could cause a variation of 500 cps. This caused issues, as I would have to repeatedly probe the cat with the Geiger counter to try and find the peak reading, with the repeated jabs seemingly irritating the subject, causing him to repeatedly wander off. This variation due to the cat's lack of co-operation would also have to be factored into the overall reading.

I asked my partner if I would be able to shave her cat's chest and mark on with an indelible marker where the best point to get a reading from on a consistent basis. This suggestion was not welcomed and resulted in harsh words; therefore, it was deemed that I would have to factor this in as an error in the experiment as this was preferable to spending the next week sleeping on the sofa. If I was to repeat this experiment, I would probably measure a part of the body that was easier to find (such as the cats anus as I am acutely aware of where this is given that it is often the first thing that I see when I wake up in the morning). Although this would not give the highest reading it would get around the issue of trying to locate the thyroid, as

I found that this would vary based on whether the cat was standing, sitting, or lying down.

The difficulty of working with a cat in a scientific environment did make me realise why we know of Pavlov's dog and the results of Pavlov's cat were clearly buried.

Conclusion:

Cats are unpleasant, unhelpful creatures and do not make useful subjects for science experiments. I now fully understand why Schrodinger wanted to kill one of the wee bastards in his experiments…

List of Latest Research Output

Optical read-out of Coulomb staircases in a moiré superlattice via trapped interlayer trions.
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In: Physical Review X, Vol. 11, No. 3, 031048, 01.09.2021.

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Visible photon generation via four-wave mixing in near infrared near-zero-index thin films.
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Greenwood, Harrison R.; Saleh, Mohammed F.
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