The Ashoka Physics Journal

SUMMER 2020

Released: Summer 2020

Cover Page Theme: 'To grab the stars, grab your desires.'
Back Page Theme: 'Sunset at Ashoka.'
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Letter From the Editor

This journal was something which was in the plans since the Ashoka University Physics Society first got some structure. It took some time but we are proud to finally be able to get the first edition of the Ashoka Physics Journal out. The team working on this was a small one, consisting of Rashmi Gottumukkala (Physics Major, Undergraduate Batch of 2020), Aditya Joshi (Mathematics Major, Undergraduate Batch of 2020) and me, but with a lot of help from Arnab Chakraborty (PhD, English Department) and Biratal Wagle (Physics Major, Undergraduate Batch of 2022), who helped in the editorial process. This journal is the result of a collective effort of students of the Physics Society, students who are not only from the Physics Department but from various other departments too; along with a lot of support from the physics professors.

The Ashoka Physics Journal is an attempt to bring the world of physics closer to the students, both to physics majors and to those who are majoring in other disciplines. It is an attempt to help those who want to know what studying physics at the undergraduate level is like get a glimpse of what the subject has to offer.

The aim of this journal is to share knowledge from both the professors and the students in a manner which is both easy to understand and entertaining to read. The work which has gone into making this journal over the last few months have been with this goal in mind. This is the first ever issue of the Ashoka Physics Journal. Everyone who has been involved in the process of making this journal a reality can only hope that it can become a part of the traditions of the Physics Society and continue on in the years to come.

Thank you.

Riya Banerjee
(Physics Major, Undergraduate Batch of 2020)
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Agnes Pockels: From Washing Dishes to Inventing Surface Science

Dr. Sabyasachi Bhattacharya, *Ashoka University*

Agnes Pockels, *February 14, 1862 – November 21, 1935*.[1]

"*My lord, will you kindly excuse my venturing to trouble you with a German letter on a scientific subject? Having heard of the fruitful researches carried on by you last year on the hitherto little-understood properties of water surfaces, I thought it might interest you to know of my own observations on the subject. For various reasons I am not in a position to publish them in scientific periodicals, and I therefore adopt this means of communicating to you the most important of them. [...] I thought I ought not to withhold from you these facts which I have observed, although I am no professional physicist; and again begging you to excuse my boldness, I remain with sincere respect.*"
– POCKELS, letter to Lord Rayleigh, January 10, 1891

"*I shall be obliged if you can find space for the accompanying translation of an interesting letter which I have received from a German lady, who with very homely appliances has arrived at valuable results respecting the behaviour of contaminated water surfaces. The earlier part of Miss Pockels' letter covers nearly the same ground as some of my own recent work, and in the main harmonizes with it. The later sections seem to me very suggestive, raising, if they do not fully answer, many important questions. I hope soon to find opportunity for repeating some of Miss Pockels' experiments.*"
– RAYLEIGH, letter to *Nature*, March 2, 1891

Published: Nature, March 12, 1891

Great scientists, and even some not so great ones, have always been receiving mails/emails from people unknown to them, imploring them to examine their discoveries or inventions and opine on them – and if they seem valuable – to help them receive recognition or, at the very least, help them do more. Most of these "crank mails" would receive what they sometimes deserve – the waste-paper box in the pre-modern era and the delete stroke in the modern days.

However, there are, and have always been, exceptions. Two of the famous examples known to many in India are the letter from Srinivasa Ramanujan to G.H Hardy and the other from Satyendranath Bose to Albert Einstein. The rest, as one says, is history. These exceptions touch our heart, evoke humility that genius can rest in unknown places and alert us to the fact that social, political and economic circumstances deprive genius of its ability to flourish and make us poorer in turn.

A lesser known example is a letter written by a German woman, Agnes Luise Wilhelmine Pockels (henceforth referred to as Agnes Pockels) to Lord Rayleigh in Cambridge that launched Surface Science as an active branch of interdisciplinary sciences. Portions of the letter, the subsequent letter from Rayleigh to *Nature* and the date of publication of her paper in *Nature* are quoted above. Both letters bear repeated readings between the lines.

Agnes Pockels was born in Vicenze, under the Austro-Hungarian rule. After her father, a member in the local military, fell ill, the family moved to Brunswick where she attended school. Women were not allowed to enter universities during that time. Pockels recalls her interest in physics, but had to be content to study physics from the books of her physicist brother Friedrich Pockels (of Pockels Cell fame) while she mostly attended to her unwell parents and looked after housework. This included cooking and washing dishes. Her scientific work stemmed from her observations of washing the dishes with water and subsequent experiments with a home-made invention, now known as Pockels Slide Trough. It was modified later by Irving Langmuir and is also known as the Langmuir Trough. The Surface Wave experiment at Ashoka is performed with a set-up whose design consists of contributions of Pockels, Langmuir and Rayleigh, without any laser, of course! However, a modernized version of the trough with minimal conceptual modification is still a commercially available research-grade instrument and is routinely used in surface science laboratories around the world.

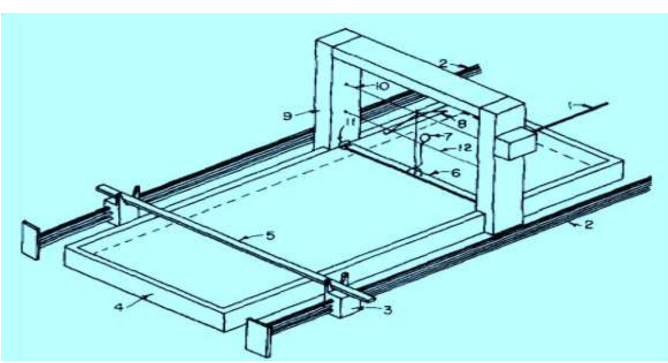

Figure 1: Pockels' Trough.[3]

A slightly modern trough, taken from the internet, is shown in Figure 1 with its approximate dimensions and its capabilities as conceived by Pockels.

- A rectangular tin trough, 70 cm long, 5 cm wide and 2 cm high filled with water to the brim and a strip of tin about 1.5 cm wide laid across it perpendicular to its length, *so that the underside of the strip is in contact with the water*.
- Variation of surface area by altering the strip position.
- Surface tension measured with an apothecary's balance to determine the weight necessary to lift a small disk, 6 mm diameter (i.e. a button) from the water.

Summary of observations in the article Surface Tension, *Nature* (1891), 46. 437:

I The surface tension of a 'contaminated' water surface varies if the surface is compressed or expanded. On compression, the surface tension decreases up to a factor of two. On expansion, it increases until a maximum value is reached, then remains constant.

II Thus, a water surface can exist in two states, a normal condition in which the surface tension remains constant if the surface size is changed, and an anomalous condition, where varying the surface size leads to a change in surface tension.

III The cleaner the surface, the more it can be compressed while the surface pressure remains at its maximum value.

IV A surface in the anomalous state can be cleaned by removing the surface layer by immersing and withdrawing a paper strip.

V The lower the surface tension, the more pronounced is the wave damping.

VI All solid bodies, no matter how clean, contaminate a water surface that is in normal state.

VII Solid materials like glass or metals increase the relative 'contamination'.

VIII Other materials like camphor or flour reduce the surface tension until an equilibrium value is reached that is different for each substance. The solid is the source of a current of 'contaminating' material. A contact line between water surface and the material current can be made visible by dusting the water with flowers of sulfur.

IX A material current occurs between surfaces with the same surface tension if the 'contamination' is caused by different substances. "Equal relative contamination by different substances does not indicate equality of that (osmotic?) pressure – in surface films – which is the cause of the material current between surfaces of equal surface tension".

X Solutions of sugar have a normal surface and a higher surface tension than pure water. Yet a piece of sugar brought to the surface causes material current and reduces surface tension.

XI "From these measurements, I concluded that (a) the surface layer of water can take up more of soluble surfaces than the bulk solution; (b) the compressed surface of a solution gets anomalous, always and only if it contains more of the dissolved substance that the bulk."

These observations in that first paper in *Nature* were the summary of ten years of work. They are left as exercises for the readers to interrogate, more than a century later, and critique comments made by others to the effect that these observations form the basis of "Surface Science". Prior to Lord Rayleigh's intervention, these results were submitted to the faculty of the University of Goettingen where her brother had studied. They received no interest. It would be an interesting exercise, left to the readers, if they would like to build a prototype of Pockels' Trough at Ashoka and test her observations with the knowledge of modern physics.

Her brother passed away in 1913 and her connection to the scientific literature ceased. But in the intervening years she published some more papers, listed below.[1]

List of Publications

Surface Tension, (1891) Nature, 46, 437.

On the relative contamination of the water surface by equal quantities of different substances, (1892) Nature 47, 418.

Relations between the surface tension and relative contamination of water surfaces, (1893) Nature, 48, 152.

On the spreading of oil upon water, (1894) Nature 50, 223.

Beobachtungen über die Adhäsion verschiedener Flüssigkeiten an Glas, (Observations about the Adhesion of Different Liquids on Glass), (1898) Naturwissenschaftliche Rundschau, 14, 190.

Randwinkel gesättigter Lösungen an Kristallen (Contact Angles of Saturated Solutions on Crystals), (1899), Naturwissenschaftliche Rundschau, 14, 383.

Untersuchungen von Grenzflächenspannungen mit der Cohäsionswaage, (Investigations of the Surface Tension with the Cohesion Balance), (1899) Annalen der Physik, 67, 668.

Über das spontane Sinken der Oberflächenspannung von Wasser, wässerigen Lösungen und Emulsionen, (On the Spontaneous Decrease of the Surface Tension of Water, Aqueous Solutions and Emulsions), (1902) Annalen der Physik, 8, 854.

Über Randwinkel und Ausbreitung von Flüssigkeiten auf festen Körpern (On Contact Angles and the Flow of Fluids on Solid Bodies), (1914) Physikalische Zeitschrift, 15, 39.

Zur Frage der zeitlichen Veränderung der Oberflächenspannung (On the Changes of the Surface Tension with Time), (1916) Physikalische Zeitschrift, 17, 141.

Über die Ausbreitung reiner und gemischter Flüssigkeiten auf Wasser (On the Spreading of Pure and Mixed Liquids on Water) (1916) Physikalische Zeitschrift, 17, 142.

Die Anomalie der Wasseroberfläche (The Anomalous State of the Water Surface) (1917) Die Naturwissenschaften, 5, 137 u. 149.

Zur Frage der Ölflecke auf Seen (On Oil Stains on Lakes) (1918) Die Naturwissenschaften, 6, 118.

The measurement of surface tension with the balance (1926) Science 64, 304.

In 1932, when Irving Langmuir won the Nobel Prize in Chemistry for his study of monolayers on solids and liquids, some commented that "part of his achievements was founded on original experiments first made with a button and a thin tray, by a young lady of 18 who had no formal scientific training". There is also a claim that she was the first person to estimate the length of a typical amphiphilic molecule to be about 1.3 nm which was slightly modified by Lord Rayleigh later. However, thermodynamic phase transitions in surface monolayers, as seen in the Surface Pressure-Surface Area (P-A) isotherms – analogous to the pressure-volume (P-V) isotherms in, say, van der Waals gases – remains the most significant and influential discovery by Agnes Pockels and survives today as a vibrant field of active research. The article in the Reviews of Modern Physics[4] in the reference section bears testimony to this discovery, by explicitly acknowledging Pockels to be the discoverer, albeit referring to the system as "Langmuir monolayers".

Postscript

The article is ended abruptly, which is both intentional and inevitable. Intentional because the conclusions of Agnes Pockels' first paper are quite a handful for careful readers who want to study this landmark paper. Written in the days when very few active scientists were engaged in scientific publications, this paper has since acquired 500 citations to date. Few greater examples are known of the power of a combination of careful observation and thoughtful analysis. And inevitable because the author is geographically separated from all his books and papers and has the Internet as his only guide.

More biographical details of Agnes Pockels can be found in the open literature. A curious detail is that she received a doctorate on her 70th birthday, the only degree since she graduated from high school.

However, one cannot overlook the role played by Lord Rayleigh, much the way of Hardy and Einstein in the other two celebrated cases, supporting the adage that only geniuses recognize geniuses. Quite apart from the generosity and high ethical standards, an extraordinary humility shines through in that he (among the giants of science of his times) was going to follow up on her work to try to settle some yet unsettled issues.

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[1] "Agnes Pockels" in *Wikipedia*. Retrieved August 17, 2020, from https://en.wikipedia.org/wiki/Agnes_Pockels.

[2] "Agnes Pockels: Life, Letters and Papers". Retrieved August 18, 2020, from https://www.aps.org/programs/women/workshops/upload/helm.pdf.

[3] "Langmuir-Blodgett Films". Retrieved August 19, 2020, from http://idol.union.edu/malekis/ESC24/KoskywebMod ules/cp_lang.htm.

[4] Kaganer, V. M., Möhwald, H., & Dutta, P. (1999). "Structure and phase transitions in Langmuir monolayers". *Reviews of Modern Physics, 71*(3), 779.

George Gamow, and the $\alpha\beta\gamma$ Paper

Quantum Physicist George Gamow was known for his puckish humour. When he and his student, R. Alpher, signed their names to the preliminary calculations of their paper, *The Origins of Chemical Elements*, in 1948, Gamow comment, "Something is missing," and, crediting Hans Bethe *in absentia*, made the signature "Alpher, Bethe and Gamow," a play on the Greek letters α, β and γ. The paper is now known as the $\alpha\beta\gamma$ paper!

Taken and modified from the biographical preface of *Thirty Years that Shook Physics*, by George Gamow. *Dover Publications, 1985* p ix.

Curves Without Lengths

Dr. Somendra M. Bhattacharjee, *Ashoka University*

Abstract

A generalization of the definition of the length of a curve allows us to describe many different types of "curves" that would defy conventional Euclidean description. Such objects, called fractals, are abundant in nature.

How is the length of a curve measured? First we choose a stick of length l, and then find out the number of times $N(l)$ we need to place the stick along the curve. The length is then given by $L = N(l)\, l$. As shown in Figure 1, this may not be a good estimate of the length. It then helps to think of an iterative procedure, where the count is recorded when the stick length is reduced to $l/2$.

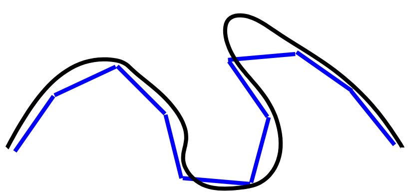

Figure 1: Measuring the length of a curve (black line) by a stick (blue line) of length l.

After n such steps, the length is given by $L_n = N\left(\dfrac{l}{2^n}\right)\dfrac{l}{2^n}$. If the large n limit exists, then the length is defined as $L = \lim_{n\to\infty} L_n$. By writing this as a sum, one can see the connection with the usual Riemann integral, viz., $L = \int dl$. We here show two examples where the limit $n \to \infty$ does not give us a nonzero number.

Cantor set: A historically important example is the Cantor set, which is actually not a curve in the usual sense. As it is seen to be a nontrivial set of intervals, not an empty set, the Cantor set is used as a test bed for many ideas.

The set is constructed iteratively by taking a closed interval 0 to 1, and then removing the middle 1/3 to get two *closed* intervals. In the next step, the middle one third of the two branches are removed leaving us with 4 intervals (Figure 2). This iterative process leaves a set of disconnected points.

First note that the lengths of the intervals removed are successively $\frac{1}{3}, \frac{2}{3^2}, \ldots$ so that the total length removed is $\sum_n \frac{2^{n-1}}{3^n} = 1$. Since the total length we started with is 1, the remaining points have no "length" and therefore cannot be one-dimensional. The set is disconnected.

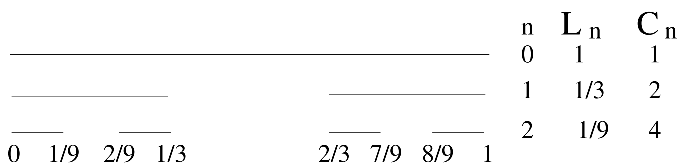

Figure 2: Construction of a Cantor set.

There is still a nontrivial structure like self-similarity. If any one part of the nth iterate is multiplied by 3, we get back the state in the $(n-1)$th iterate. This geometric structure is described by a different dimension, to be called the *self-similarity dimension* or *Hausdorff dimension*.

For a regular object like the Cantor set, the pattern is obtained by scaling the nth iterate by a scale $b < 1$ and combining C_b of them. Here, $b = 1/3$ and $C_b = 2$. On successive rescaling how the number grows is given by the Hausdorff dimension $\boxed{d_{\rm H} = \dfrac{\ln(C_b)}{\ln(1/b)}.}$

The occurrence of $\ln 3$, or log base 3, is not accident. It comes from the scale 1/3 under which the Cantor set is scale invariant. If we choose an arbitrary scale factor, say $b = 1/2.9$, the scale invariance of the Cantor set is not obvious. This existence of a special scale, here 1/3 or its powers, is an example of *discrete scale invariance*. A discrete scale invariance leads to highly nonintuitive complex dimensions.

Koch curve: A Koch curve is defined in Figure 3(a). Instead of deleting the middle 1/3 as in the Cantor set, we add an extra piece increasing the length of the line. This curve has the following properties:

1. A point disconnects it as for a curve. One says, its *topological dimension* $d_{\rm t} = 1$. Note that the

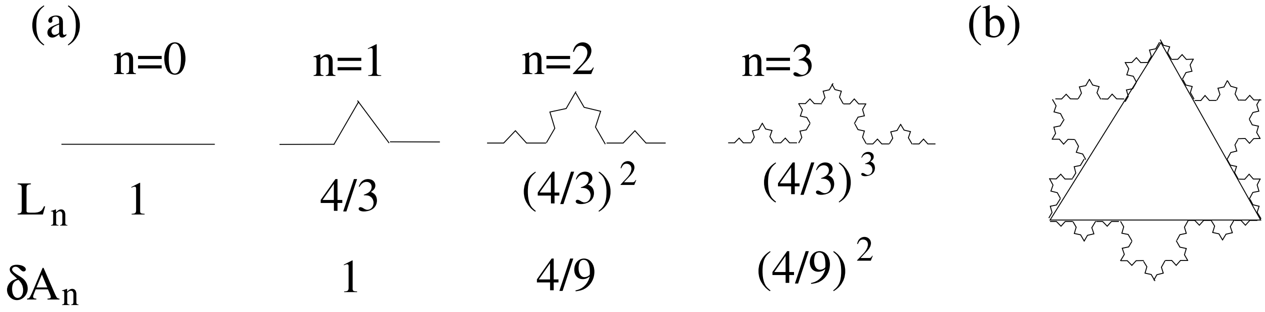

Figure 3: (a) Iterative construction of the Koch curve. An interval of length 1 is divided into 3 equal parts. The middle segment is replaced by an equilateral triangle of side length 1/3 without the base. This procedure is repeated for each segment. The length of the curve (L_n) and the area (A_n) under it for the first few generations are given. (b) Similar construction with a triangle. After infinite iteration we get a closed loop of infinite perimeter but of finite area.

topological dimension of the Cantor set is zero.

2. The generation-wise lengths are $1, \frac{4}{3}, \left(\frac{4}{3}\right)^2, \ldots \left(\frac{4}{3}\right)^n, \ldots$ so that the length diverges ($L_n \to \infty$) as $n \to \infty$. However the area under the curve is $1 + \frac{4}{9} + \left(\frac{4}{9}\right)^2 + \ldots = \frac{9}{5}$.
3. For a stick length $l_n = 1/3^n$, the number of sticks is $C_n = 4^n$. For a scale factor $b = 1/3$, the ratio of the two numbers $C_{n+1}/C_n = 4$. The fractal dimension is $\boxed{d_{\mathrm{f}} = \lim_{n\to\infty} \frac{\ln(C_n/C_{n-1})}{\ln(1/b)} = \frac{\ln 4}{\ln 3}.}$

If we take $\epsilon = 1/3^n$ as the length of the measuring stick with $\epsilon \to 0$ as $n \to \infty$, then the measured length $(4/3)^n$ is dependent on the scale via $n = -\ln\epsilon/\ln 3$. We may generalize this result. The length measured at scale ϵ behaves as $\boxed{L(\epsilon) \overset{\epsilon\to 0}{=} L_0 \epsilon^{-\alpha},}$ with $\alpha = d_{\mathrm{f}} - d_{\mathrm{t}}$.

For those cases where the two dimensions match (as for a "traditional" curve), the length is independent of the scale. In such cases, one may talk of the length of the curve, and such curves are called *rectifiable curves*. Figure 1 is an example of this.

We see a curve of topological dimension 1 but of a fractal dimension between 1 and 2. The Koch curve is also an example of a continuous but nowhere differentiable curve. As a closed curve, Figure 3(b), we get a continuous curve enclosing a finite area, though of infinite length.

Epilogue: With the Cantor set and the Koch curve as examples, we introduced the idea of measuring the length of any curve, and in the process defined fractals and their dimensions.

Just to see how these special sets confront our traditional knowledge, try to evaluate $\int_0^1 f(x)\,dx$, where $f(x) = 1$ whenever x belongs to the Cantor set, but zero otherwise.

NOTES

- For more details see, "What is Dimension" by S M Bhattacharjee, in "Topology and condensed matter physics" (Springer, 2017). A part of this note is taken from this article.
- See Timothy J. Rudge etal, *Cell Polarity-Driven Instability Generates Self-Organized, Fractal Patterning of Cell Layers*, ACS Synth. Biol. **2**, 705 (2013) for an example of the Koch curve in Biology.

The Physicist in You

Dr. Bikram Phookun, *St. Stephen's College, Delhi University*

I recently listened to an interview with Jean-Christophe Rufin, a French diplomat, writer, and doctor. After being trained as a doctor, he worked with *Médecins Sans Frontières* (Doctors Without Borders), an international organization that does voluntary work all over the world. Later he was a diplomat and became an ambassador. In his forties, he started writing novels; one of his books won the Prix Goncourt, France's highest literary honour, and he is now a member of the *Académie française*, France's most elite group of writers and thinkers. In the interview, which was about the creative process behind his writing, he was asked – How do you think of yourself? As doctor, diplomat, or writer? His immediate response was – I think of myself as a doctor. The doctor in him remained deep down – because of his *formation* in medicine – no matter what he happened to be doing on the surface.

The French word *formation* stands for the English word training, but it is more evocative of the lasting effects of deep training. There are disciplines that shape you, and medicine is certainly among them. Physics, I am sure, is another.

Some time back, while I was at Ashoka, I was invited to speak at a meeting of school counsellors. I explained how physics prepared students for virtually all professions. At the end of the talk the organizer, who had been listening very attentively, asked me, "In that case, should we encourage all students to major in physics?" Well, I would not go so far, but I certainly think that the foundation laid by physics can support a wide range of disciplines: mathematics, computer science, engineering, geology, mathematical economics, biology, philosophy, among others – in addition of course to all branches of physics and astronomy.

The reason for this is that learning physics is not just about doing physics, it is also about thinking like a physicist. And this kind of thinking turns out to be effective far outside the domain of physics. I see four reasons for this: physics trains us to build and verify hypothesis in a way that no other discipline does; its theoretical explanations have a hierarchical structure that invites correction and improvement; its subtlety and richness teach us to step back and notice; and its difficulty and intricacy require not just hard work but work that is self-reflective. Let me elaborate.

Theoretical physics is mathematical in its formulation, but it is not mathematics; its concern is to explain phenomena. These phenomena are not merely observed but probed using techniques that reveal their inner workings – this is experimental physics. Theoretical physics builds models to explain phenomena from the bottom up, and in doing so often discovers both theoretical and experimental possibilities earlier unimagined. Experimental physics may be guided by theoretical ideas and preconceptions in what it probes, but in realizing experiments it often discovers unsuspected phenomena that require other experiments and new theoretical explanations. Theoretical physics and experimental physics thus support and strengthen each other. There is a back-and-forth between hypothesis-making and corroboration that, so far as I can tell, is unparalleled in its depth and breadth. The neuroscientist Stanislas Deheane, who has done fundamental work on how the brain acquires language and mathematics, and more generally on how we learn, emphasizes that learning is never a one-way process. Our brain, he says, teaches itself by projecting hypotheses onto the world it perceives. Using what it sees, it improves its hypotheses, projects them once again, and so on. Physics thus uses and refines the brain's natural methods. It is not surprising therefore that a strong intuition about the physical world is a natural by-product of training in physics.

The business of theoretical physics is to build models. The models of physics, however, are different from those in most other disciplines, for undergirding them is a set of fundamental laws and principles. Of course these laws and principles are themselves models – but they are models of a deeper nature. For example, to explain how light propagates through a glass we use, at the deepest level, Maxwell's equations – the fundamental description of electromagnetic waves, of which light is an example – and, at a more superficial level, a model of the properties of glass. To understand how a rocket re-enters Earth, we use, at the deepest level, Newton's laws of mechanics and of gravity, and, at a more superficial level, a model of the properties of the atmosphere. In other words, a model in physics is layered hierarchically. When a proposed explanation does not work, it can be corrected layer by layer, with the most superficial layer being modified first. The models of physics possess a structure that suggests how they can be modified when they don't agree with observations. As a consequence, anyone trained in physics learns to distinguish what is important, and ought not to be lightly modified, from what is less important, and can more easily be modified.

The fundamental laws of physics very strongly constrain the kinds of models that are acceptable in physics. As Richard Feynman put it, physics requires imagination in a straitjacket. This may seem like a limitation, but that is far from true. Working with extremely tight constraints, theoretical physicists nevertheless have room to discover and explore. This has to do with a marvellous and profound property of the mathematical structures of theoretical physics: they not only explain the limited set of phenomena that led to them, they contain so much more that no human imagination can circumscribe their possibilities. As new possibilities are discovered within the theoretical structures, it often happens that experiments can be designed to discover them in the real world – and they are. When Dirac found a negative energy solution in his equation, he interpreted it as corresponding to anti-particles; experiments revealed that such particles exist. Feynman says that nature's imagination far surpasses our own. That is true. And because nature's imagination is so vast the "imagination" of the fundamental descriptions of nature arrived at by physicists is far greater than that of their discoverers. The basic equation of quantum mechanics, for example, was discovered by Erwin Schrödinger after much struggle, and in a manner that might suggest that he could just as easily have arrived at some other; in fact he hesitated between his famous equation and other possibilities. But once established, it proved not just to have beautiful and physically appropriate mathematical properties but to describe and predict a bewildering variety of phenomena, many now observed and most far beyond the wildest imaginings of Schrödinger or anyone else. The subtlety and richness of nature, and thus the subtlety and richness of fundamental physics, are so great that the only way to get a sense of them is to look very carefully. Looking carefully means not only examining them up close, but also stepping back for a detached, panoramic view, also looking at them from unusual angles, also allowing one's peripheral vision to pick up their faintest scintillations. To do physics is to learn the art of noticing.

Physics, we see, is a difficult and intricate business, just as many sports, medicine, music, and dance are. A difficult discipline is one in which talent gets one nowhere unless it is supported by hard and regular work. The divinely gifted cricketer Sachin Tendulkar would happily practice twelve hours a day. The incomparable violinist Jascha Heifetz said – if I don't practise one day, I know it; two days, the critics know it; three days, the public knows it. But physics is not just difficult, it is also intricate. An intricate discipline is one in which hard work gets one nowhere unless it's done with reflection. The classical guitarist Pavel Steidl said something at a master-class in Kolkata (attended by a friend of mine) that I have repeated over and over again to my students – don't over-practice, but when you practice make sure that you notice your mistakes and correct them. The difficulty and intricacy of physics is often regarded as a barrier by undergraduates, and the well-meaning sometimes tend to ask themselves how they might make the subject easier. In my opinion, this misses the point: learning physics means *embracing* difficulty, in the same way that learning to play an instrument or to climb mountains or to write poetry does. The difficulty and intricacy of physics are not hindrances, they are rewards. When we accept them whole worlds open up to us.

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Relevance of Soft Matter Physics in Undergraduate Education

Dr. Pramoda Kumar, *Ashoka University*

Pedagogy of undergraduate physics, to a large extent, is structured in a particular way throughout the world for a good reason and this leaves us with very little room to introduce any new topical courses. I guess, one of the most challenging tasks for the founding Physics faculty of Ashoka would have been putting together – within the University's liberal and inter-disciplinary pedagogical framework – a concise syllabus for the Physics major without compromising on the quality and depth of the course components and its present day relevance. Introducing soft matter physics in the undergraduate curriculum is definitely one of the much needed initiatives at least in the Indian context.

What is soft matter science and why should it be a part of physics training at the undergraduate level? Broadly speaking, most of the mundane things that we use in our day-to-day life like toothpaste, hair gel, ice-cream, milk, soap and paint are some of the examples for soft matter. These materials show a very large change in their physical properties (usually non-linear in nature) for an external perturbation and thermal fluctuation, and these properties cannot be deduced from the properties of its basic units. As French physicist de Gennes said in his 1991 Nobel lecture, *complexity* and *flexibility* are the two salient features of these soft materials.

Soft matter physics helps students get a better grasp of most of the abstract physical concepts of thermal and statistical physics and continuum mechanics. For example, I would argue that soft matter is the right system to understand the difference between energy and entropy and their relative contribution for the stability of a phase of matter. The characteristic length and time scales of these systems are such that one can easily develop many laboratory experiments without the need of any high end equipment. For example, a demonstration of phase transition in a liquid crystalline sample can be set up with just an ordinary optical microscope with a pair of polarizers and a hot-stage. The beauty of this simple demonstration is that you can go from the perfectly ordered crystalline phase to completely disordered isotropic phase via the rich spectrum of partially ordered liquid crystalline phases just by changing the temperature of the sample. As soft matter physics is a relatively new area with many unsolved scientific questions, it offers plenty of opportunity for the students to work on open ended research projects while learning the subject.

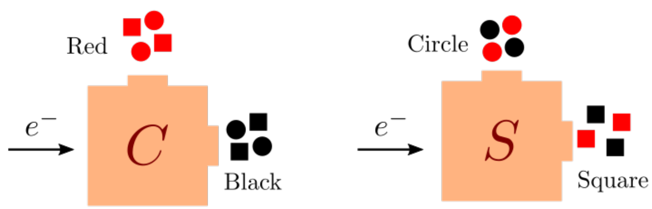
The theoretical concepts and experimental techniques of soft matter physics are directly applicable in other fields of science, particularly in biophysics. The physics of the animated world is still very much in its infancy. As it is notoriously difficult to isolate and study the basic phenomena in biological systems, physicists often study model systems based on soft materials. For example, lipid bilayers formed by surfactant-water system can be used to gain basic understanding of working mechanism of biological membranes, and myelin structure formation at the interface of liquid crystals-aqueous surfactant solutions can be used to understand the myelin sheath around the axon of a neuron. If there is any quantum jump in our understanding of biological systems, I presume, that can only be achieved through the powerful concepts and techniques borrowed from soft matter physics.

The Spooky World of Quantum Mechanics

Philip Cherian, *Ashoka University*

This is a story about electrons and how they behave. I feel obliged to warn you before we begin, however: it's an unsettling story, perhaps the most unsettling story to ever have come out of physical experiments. The experiments I'm going to describe have all actually been performed (not necessarily with electrons, and they have been slightly changed for dramatic effect) and the results are exactly as I describe them.

Consider a bunch of happy little electrons, going about their own business. Let us say that these electrons have two properties that we are interested in, that we call shape and colour. They can be either square (■, ■) or circular (●, ●), or red (⊡) or black (⊡). Let us also say that someone has made "colour" and "shape" machines that can sort these electrons for us (see Figure 1).



(a) A colour sorting box (b) A shape sorting box

Figure 1: Colour and shape sorting boxes: electrons that come out of these boxes are found to all be (a) either red or black, or (b) either circle or square. In every case, the ratio is 50:50.

Let us assume that we are working with a large, randomly chosen sample of electrons. Experiments are performed to find out how many electrons are black and how many red, and it is found that half of all the electrons sent into the box are black, and half red. A similar result is found with the shape box, where half are found to be circular and half square. (It is important to mention that the actual mechanism of the boxes is irrelevant: scientists have made many such boxes in many different ways, and the results have always been the same.) A natural question to ask at this juncture is the following: are colour and shape correlated? This can easily be resolved by considering all possible colour and shape combinations: pass the electrons first through a colour box, and then through a shape box, and count the different ratios of both types. Then do the same thing by passing them through a shape box and a colour box. The results, in each case, show that there are always 50% of each type. It seems that there is no correlation between colour and shape. Suppose now we take the electrons that leave the black end of a colour box, and pass them through another colour box, as shown in Figure 2, then they are *all* found to be black. Indeed, this is the **meaning** of a colour box. Something similar happens with a shape box.

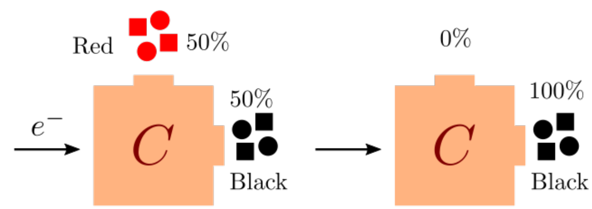
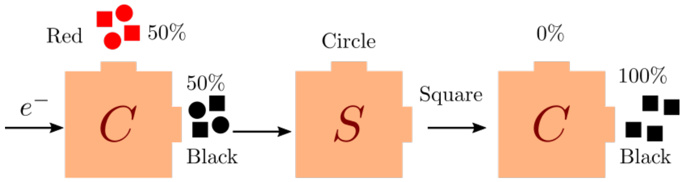


Figure 2: Of all the electrons produced, 50% are red and 50% black. If the 50% are found to be black are passed through another colour box, they are *all* found to be black.

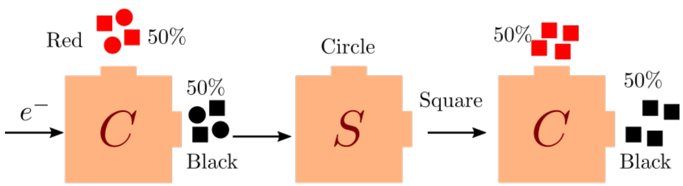
Everyone with me so far? Good. Now let's consider three different experiments that go from simple to complicated. In each of the cases below the electrons are sent in **one at a time**, so that they don't have a chance to interact with or influence each other. The percentages given next to the boxes are with respect to the number of electrons that enter *that box*.

The Experiments

Experiment 1: Consider a case where we pass the electrons one by one through a colour box, and then collect only the black electrons and pass them through a shape box. We then pass only those of the resulting electrons (which should all be square) through *another* colour box. What would you expect to happen? You would probably reason that since the electrons you sent through the shape box were black, then those that exited the shape box were also black (albeit square), and so when you measure them again you'd expect them to all be black. However, you would be wrong. What actually happens is that we get 50% each of black and red electrons!



(a) What you would expect to happen in Experiment 1



(b) What actually happens in Experiment 1

Figure 3: (a) The results one would expect from Experiment 1, and (b) what actually happens. The conclusion is simple: shape measurements seem to randomise colour.

This is very strange, as all we have done differently in this case is place a shape box in between two colour boxes, and yet the results have changed. You reason therefore that shape and colour *must* be correlated: it appears that the measurement of shape causes the colour of each electron to become randomised.

Experiment 2: Let's now move to a slightly more complicated problem: we send only black electrons are through a shape box. Both shapes move along different paths, "bounce" off mirrors and are recombined in a "beam splitter" (a fancy mirror that joins beams) and passed through another shape box.

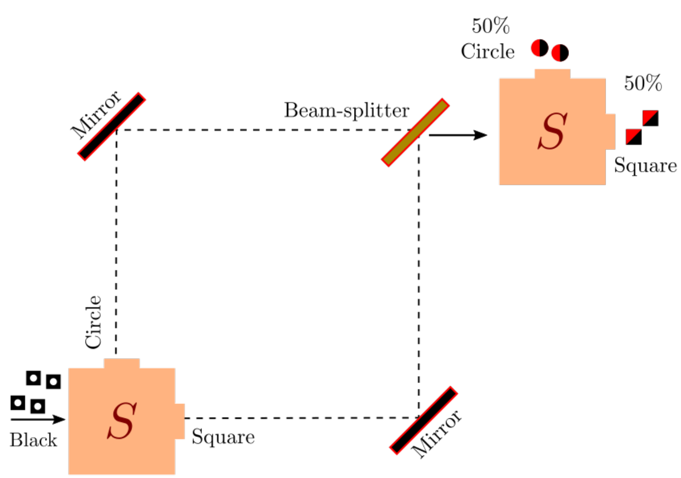
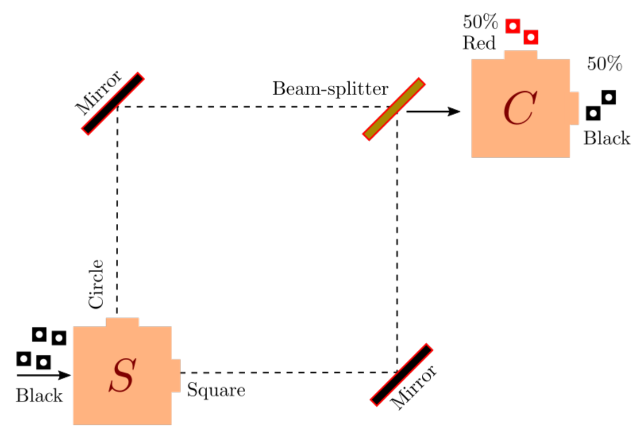


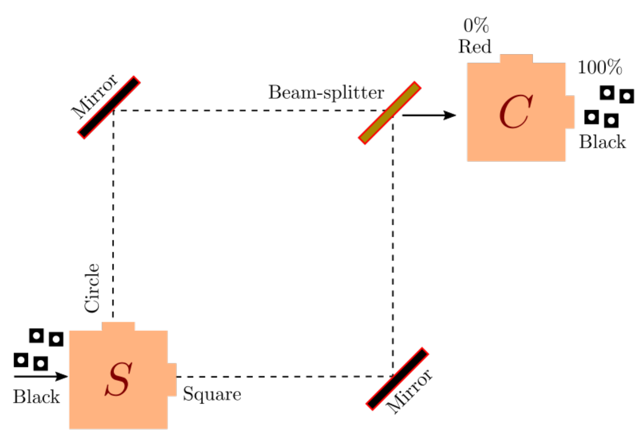
Figure 4: What you would expect to happen (which is also what actually does happen) in Experiment 2: the shape measurement randomises the colours.

Using the results of the previous experiment, since we've seen that when electrons of a certain shape enter a colour box their colours are 50:50, perhaps this means that when electrons of a certain *colour* enter a shape box, their *shapes* are randomised? In other words, perhaps there are 50% of squares and 50% of circles, which then recombine at the beam splitter, again producing a 50:50 mixture of squares and circles. Happily, this is indeed exactly what we see. Whew! Our intuition is not completely wrong, and we move on feeling perhaps a little overconfident. But wait, here's where it starts to get *really* weird.

Experiment 3a: Let's now change the measurement at the end to a colour measurement. What now? Well, since we seem to think that shape measurements randomise colour (as we've seen – or rather, think we've seen – in the previous experiment), perhaps this means we would get 50:50 of red and black. Too bad! We get 100% of black electrons!



(a) What you might expect to happen in Experiment 3a



(b) What actually happens in Experiment 3a

Figure 5: Despite measuring the shape, when the colour is measured again all the electrons are black.

Not a single red electron is found. Black electrons went into the first shape box, and only black electrons were found exiting the colour box. So you see that what we've seen so far is even more puzzling than we thought. It's not simply that the measurement of shape randomises colour and the measurement of colour randomises shape, it's far more insidious: it seems as though the *knowledge* of the shape precludes knowledge of the colour, and knowledge of the colour precludes knowledge of the shape. Since in Experiment 3a we couldn't know the shape of the electrons (they were both mixed at the beam splitter) we were able to know everything about their colour!

Experiment 3b: You're annoyed by this, and rightly so. You decide to push Nature into a corner, because she's really behaving rather badly. You take the same experiment that you just carried out and you now place a wall along one of the arms (say the square arm). Furthermore, you don't want these sneaky electrons talking to each other, and so you make the arms millions of kilometres long, so that no information about the existence of the wall can get to an electron going along the other arm.

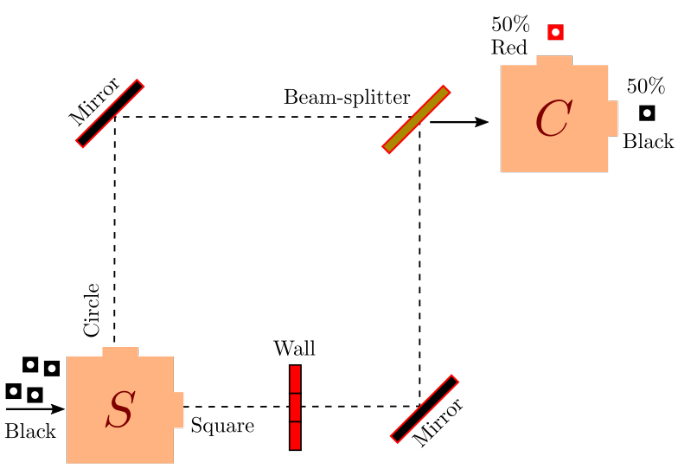


Figure 6: Experiment 3a with a slight modification: a wall is placed blocking the square arm, and the arms are made so long that the electrons can't communicate with each other. Analysing this 'classically', we exhaust all logical possibilities. We need a new word to describe what's going on.

Let's think this through: in this case, we *know* that the electrons that reach the beam splitter are all circular (since the square path has been blocked). From our earlier analysis, you should realise that if we *know* the electron's shape, then its colour should be completely random. And this is indeed the case! We could do the same experiment, with the wall along the circle path and (happily) we'd get the same answer. But remember, we're sending **one electron in at a time!** So what did this electron do? Well, let's examine the possibilities that logic allows us:

1. **It took the circle path:** Well, this is not possible, since if all electrons did this, there would be no difference between the experiments with and without the wall, but there certainly is!
2. **It took the square path:** Well, that's not possible either, since this path was walled up.
3. **It took both paths:** This is tempting: perhaps our sneaky little electrons "split" into two, and took both paths simultaneously. The problem is, we could put a detector along the paths and we would **never** find half-an-electron. Electrons come in fixed lumps, and so our electron must have taken one path or the other.
4. **It took neither path:** This is just silly, I hope you don't need me to explain why this isn't the case, but even so: if we walled up both the arms, no electrons would be detected at all.

Superposition

So what are our pesky little electrons doing? It looks like all logical possibilities have been exhausted, so they must be doing something we could not possibly dream of. We call this new "state" of being (which is simply a name for something we don't understand), a *superposition*. As the electron exits the shape box it does not go along the circle path and it does not go along the square path and it does not go through both and it certainly does not go through neither: the electron exists in a *superposition* of going along the square path and the circle path *at the same time*.

As to what this truly means (other than "none of the above"), we don't know; our language and our "intuition" are woefully inadequate to describe the quantum world, and one must be wary of drawing false parallels with everyday experience. But is this truly surprising? After all, we are trying to fathom the deepest mysteries of the Universe using a language that was originally invented to tell another apes where the ripest fruit was.

A Journey in Modelling: From the Universal to the Fickle-minded

Ojasvi Khare, *Indian Statistical Institute, Delhi Centre*

I am pursuing a PhD in Economics. So why am I writing in a physics journal? The simple answer is that I was a teaching fellow in the physics department at Ashoka University (having completed a masters in physics). What, then, do I do in economics? I work on bounded rationality and on theories that try to axiomatise human *economic* behaviour and explain the choices we make under various contexts.

Let's start with how we build mathematics, which is the formalism used to present economic and physics theories. Axioms are where the story starts. Axioms can be interpreted in various ways when used in the context of physical theories with empirical content. But in mathematics, these are the statements that are most palatable and/or reasonable starting points, such that the resulting theory is consistent and generates some "strong" results. Some examples are Peano Axioms or Zermelo-Fraenkel axioms, the minimal set we need to create a theory that accommodates the current mathematical progress. After setting down the axioms we "do" maths to prove lemmas and theorems. Doing maths involves following a logical set of operations within the axiomatic framework – if we hit any roadblock, contradictions or absurdities but haven't made any algebraic errors, we go back and examine the axioms.

In physics, axioms (or laws/principles) are generally some observable "facts" (that have been experimentally verified to an acceptable degree) or geometrical considerations that may emanate from our experience of the world. For instance, the constant speed of light, the constancy of the speed of a classical free body in flat space, or physical observables in quantum mechanics that have to be real and hence, eigenvalues of self-adjoint operators. We then "do" maths to make some more observable predictions and check them out using "experiments". Some axioms like the principle of least action may not be directly observable but do predict observable phenomena. Experiments inform theory and theory lays out a path for future experiments to verify or refute the results. They work in a symbiotic manner creating a representation of the physical world we live in using the language of mathematics.

Although physics theories can be domain or scale specific, the results under the stated conditions are universal, and as far as we know, immutable; and if experimentalists determine an anomaly, any old theory has to accommodate it, shrink its domain, present a new interpretation, or just be replaced by a new theory. Unfortunately, we can't call physical nature unreasonable. Another important point to note is that objects/particles (like classical point objects or fundamental particles) are identical in physical theories.

But, the interesting thing in the context of human behaviour is that it is demonstrably not constant or infinitely repeatable. It is in fact informed by gender, social context, friends, environmental factors (ads, peer pressure), etc., and can evolve over time in complex ways. Let us understand what we mean by (neo)classical economic rationality – individuals are expected utility maximisers or maximise using a single linear order called "rationale". The context here is that the individual has to choose an alternative from a set of alternatives called a "menu". What we will observe in the behaviour of a (neo)classical individual is that it follows (what we call) weak axiom of revealed preference – that is if she rejects an alternative (say, apple) in presence of another alternative (say, banana) in any menu then whenever banana is present in a menu, she will never choose an apple. This behaviour is "rationalised" by assuming that the individual has a utility attached to alternatives, meaning that she can rank them and chooses the best-ranked alternative according to the ranking. This kind of individual will never show "cycles" in her behaviour, that is, choose 'a' from {a,b}, 'b' from {b,c} and then 'c' from {a,c}.

That essentially entails that (neo)classical rational humans are super-humans who can compare all possible alternatives/outcomes objectively and choose what is best according to them and condense all this knowledge in "one" unified rationale or criteria. But observing humans has shown us that humans do have "cycles" in behaviour, in essence implying that maybe we use multiple criteria. Other empirical studies have made us think that maybe we can't compare all alternatives or have restricted attention, etc. That is, in essence, bounded rationality.

In recent decades experimental economists have started studying human behaviour in labs under test conditions, trying to single out behavioural patterns and anomalies, giving them stress tests and figuring out how long the mind engages in decision making. We have been able to tease out social biases, the effect of scarcity, effect of priming, order of giving instructions, etc. We have seen that individuals reverse their decision in between menus or presentations.

The main idea that needs to be encoded in our theories is that humans employ finite cognitive resources in solving each problem, since using them may be fatiguing or time-consuming. Imagine that in order to buy a bar of soap you had to begin by comparing all possible products in the market based on each ingredient, price per gram, smell, outcomes (soft skin); eventually deciding the winner and then doing it for all items on your grocery list.

We can attribute a lot of our decisions to be taken using short-cuts like status quo bias (buy the toothpaste that your family has been using), being primed by actions around us, following brand ambassadors and self-styled gurus, etc. We also observe individuals overestimating probabilities of winning a lottery or death rates of COVID.

What bounded rationality does is that it allows for various other behavioural patterns (axioms) in theories and "endows" individuals with mathematical objects, "allowing" them to follow complex heuristics like having multiple criteria, cognitive limitations, friends that convince them, advertisements that entice them and maybe a big brother "nudging" them.

Obviously humans might not have utility functions, linear orders, etc. in their head as they are purely theoretical constructs, but we can ask the question, what has to be the structure of such mathematical constructs that they reproduce empirically observed behaviour? Representation theorems then, help us "rationalise" an individual's behaviour by reverse engineering and obtaining their preferences, objectives and heuristics from their choice behaviour.

So coming back to the question, what do I do? I try to figure out the "mechanics" of these cognitive processes, see how observed behaviour can be mathematically accommodated in axiomatic theories.

**I thank Dr. Bikram Phookun, Dr. Abhinash Borah, Shiuli Chatterjee, Raghvi Garg, Nymphea Noronha and Ishan Mehandru for valuable discussions and suggestions for the manuscript.*

The Basics of Astronomy

Ankit Shrestha, *1st Year B.Sc (Hons.) Physics*

Astronomy is one of the oldest forms of science which dates back to ancient the Mesopotamian and Greek civilisations. They studied the motion of heavenly bodies and questioned our position in the universe. But have you ever wondered how and why astronomers study the seemingly random patterns of stars in the sky?

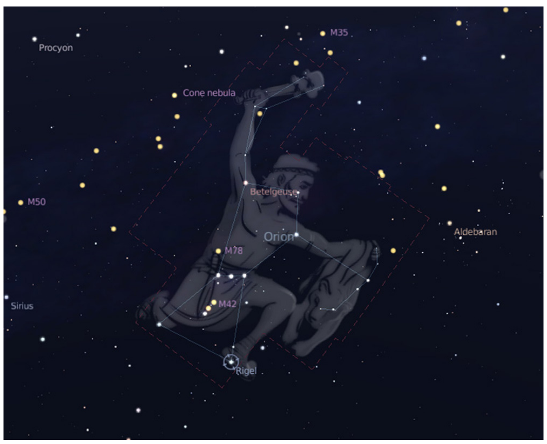


Figure 1: The Orion Constellation: the figure of the man indicates the Constellation and the stars connected by the lines to form the image is the asterism.

It is impossible to study the patterns and motion of countless stars if we study the entire sky as a single entity. Thus, astronomers have divided the sky into various sections, like the division of land in a vast field. Each section of the sky is known as a **constellation** and is named after a mythical figure. Now, each constellation has its combination of stars, galaxies, nebulae, and other heavenly bodies. Since stars are visible to the naked eye and fixed in their position with respect to nearby stars, astronomers have attributed a signature pattern of stars to each constellation. Such patterns are known as **asterisms**, and finding these asterisms is the key to study the night sky. Some famous constellations include Orion (seen in Figure 1), Ursa Major, and Zodiac constellations like Taurus and Gemini.

As the Earth rotates around its axis, the stars and other heavenly bodies move accordingly in the sky. It is evident that the Earth rotates around its axis once every 24 hours. Due to this motion, the stars on the sky seem to rotate around a point with the same time period. There are two such points in the sky, one directly above the North Pole and the other directly about the South Pole. An observer can only notice one of the two points based on the hemisphere of observation. Luckily, there is a star at the same point in the northern sky, which is commonly referred to as Polaris. It is easy to find the northern pole star: locate the two bright stars at the top of ladle shaped asterism in Ursa Major. The extrapolated line joining the two stars leads directly to the Polaris (Figure 2).

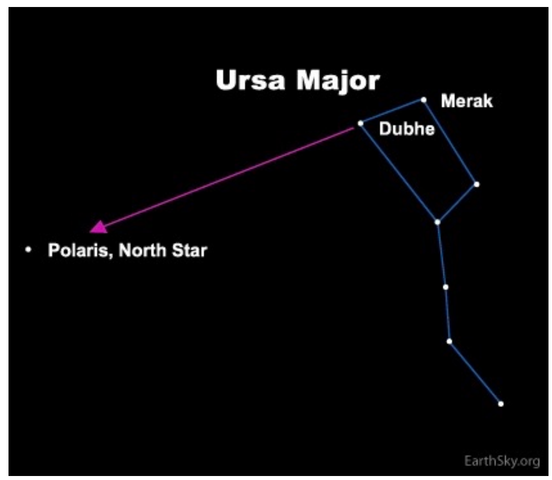


Figure 2: The two bright stars in Ursa Major − Merak and Dubhe − point towards the North Star, Polaris.

We can extract some information about the location of the observer from the pole star alone. If the observer can see Polaris, he must be on the northern hemisphere of the earth. Moreover, since Polaris is directly above the North Pole, we can deduce that the observer is facing the **North** direction. Ancient travelers used this technique to navigate through the vast oceans during the night. Besides that, the altitude of Polaris tells us the latitude of the observer (Figure 3). If the observer is exactly at the North Pole, he will notice the pole star directly above his head, a point commonly referred to as the **Zenith**. For every latitude below the North Pole, the altitude of Polaris decreases by the same angle until it reaches the horizon at the equator. Thus, people at the southern hemisphere cannot observe the Northern Pole Star as it does not rise above their horizon.

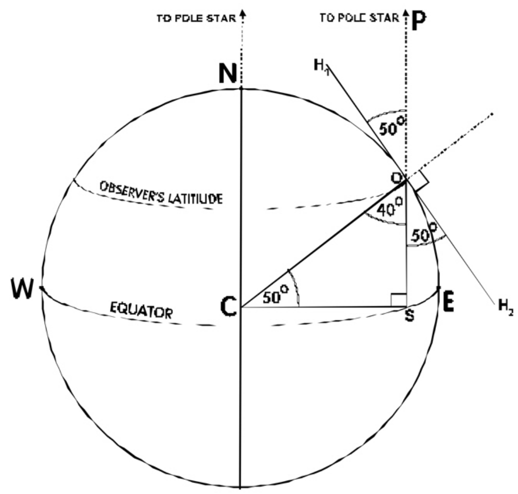


Figure 3: At a latitude of 50°, simple geometry shows us that the pole star too appears at a height of 50° from the horizon. The line H_1-H_2 depicts the horizon at a latitude of 50°.

Along with its rotation, the Earth also revolves around the Sun throughout the year. The observable constellations and their constituent heavenly bodies differ throughout the year as we travel around our central star. With basic knowledge of the constellations, observers can tell the time of the year up to the precision of a month for the given location. One efficient way to deduce the month is by studying the zodiac constellations. Since the solar system is flat (unlike Earth), the Sun and other planets follow a path in the sky, commonly known as the **ecliptic**. The path covers thirteen out of eighty-eight defined constellations, and those constellations are known as the **Zodiac Constellations**. Most people are familiar with these constellations as their sign on the horoscope. The Sun spends roughly a month on each constellation, meaning that the position of the Sun lies within the defined boundary a given constellation. Thus, one can roughly estimate the time of the year by memorising the sequence of zodiac constellations and noting the visible zodiac constellations at night, thereby estimating the current constellation where the Sun is positioned. Since each constellation roughly corresponds to a month, the observer can deduce the time of the year up to the precision of a month just by simple observation (Figure 4).

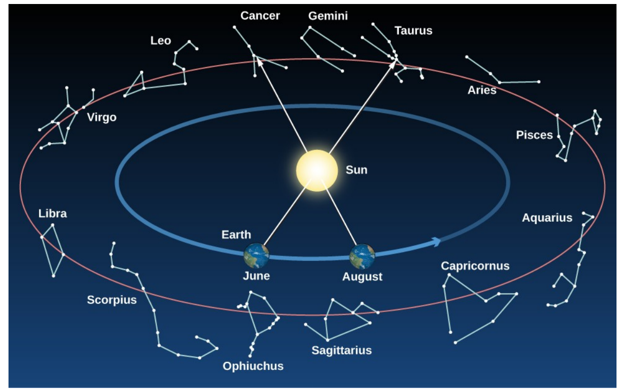


Figure 4: There are thirteen zodiac constellations which lie on the ecliptic plane. The blue circle shows Earth's orbit around the Sun. In every month, the constellation that the Sun obscures from our line-of-site is associated with that month. So, Taurus is associated with the month of June, and Cancer is associated with the month of August, as this figure shows.

The act of recognising patterns of stars in the night sky is an art and it comes with a lot of practice. Luckily, there are virtual planetarium softwares like **Stellarium** which contains maps of the sky: division of constellations and patterns of asterisms. Since we now have the basic understanding of how and why people study basic astronomy, I urge everyone to observe the motion of heavenly bodies in the night sky and experience the rotation and revolution of the Earth through your own eyes while defining your position on Earth and in this vast universe.

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Furballs, Milankovitch and a Popsicle Earth

Tatsam Garg, *2nd Year B.Sc (Hons.) Physics*

Isn't there something about Wooly Mammoths that is fascinating? It's hard to glance at an image of one and not return for a closer look. Speaking of mammoths, why do you think the Ice Ages occurred? Or even cooler, how did the "Snowball Earth" come into existence? Was it a one-time phenomenon or cyclic? Are they gradual changes or rapid shifts triggered by something?

While there have been only two known Snowball Earth events in the entire history of the planet, Ice Ages have been proven to be cyclic phenomena that occur roughly every 100,000 years. To understand the mechanism behind this, it's important to understand that the Earth's climate is entirely determined by the energy we receive from the Sun. The incident solar energy is the dominant source of energy on Earth. This, along with the fact that Earth is a pretty good black body, allows us to determine the role that incident solar energy plays in determining the surface temperature of a planet using the Stefan-Boltzmann law. We obtain the result in terms of the incident solar power per unit area, which we'll call the *solar constant*. A higher solar constant would mean a hotter Earth while a lower one would mean a cooler Earth.

The solar constant isn't a fundamental constant or even a constant for that matter. It's dynamic, constantly fluctuating every decade, every month, even throughout the day. These fluctuations, however, are insignificant for the phenomenon in the time scales that we're interested in. So what causes such massive changes in the solar constant that can change the face of the Earth? The answer is the Milankovitch cycles. As Figure 1 illustrates, these are cyclic changes in three crucial orbital parameters of the Earth.

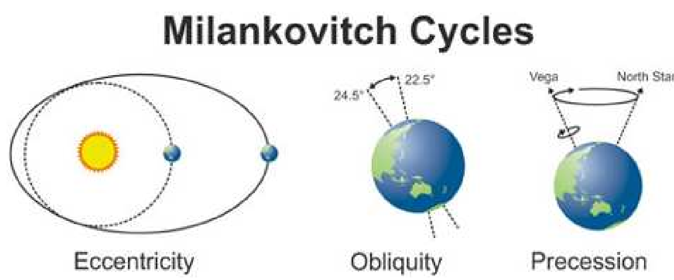

Figure 1

A combination of these three cycles is what drives the cyclic changes in the solar constant at the time scales of tens of thousands of years.

But how exactly is an Ice Age triggered? From the Milankovitch cycles, ice age patterns ought to closely mimic the Solar Constant. Is this the case?

We're going to bring in another player. Remember when I said that the Earth is a pretty good black body? A black body is only as good an emitter as it is an absorber. It turns out that a fraction of the Solar Constant is reflected from the surface of the Earth instead of being absorbed. This reflectivity of a planet is called its "albedo". Albedo can be due to a variety of things – clouds, snow, ice, tree cover, etc. Our new player is something called the ice-albedo feedback effect. As the solar constant lowers, the temperature of the planet decreases. This leads to increased ice formation and consequently higher ice cover on the planet. Increased ice cover increases the reflectivity, or the albedo, of the planet. Now, even less solar power is absorbed, thus even further decreasing the temperature and in turn causing higher ice cover, and consequently... You get where I'm going with this. The planet gets into a feedback cycle where even small changes in the solar constant could have drastic implications on the temperature.

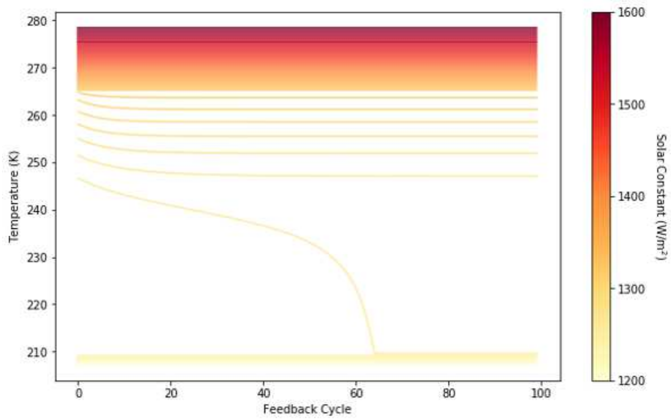

Figure 2: Stabilisation of Planetary Surface Temperature over several ice-Albedo feedback cycles for **decreasing** solar constants. Solar constant ≈ 1250 W/m^2 acts like a cut off value for which the temperature stabilises only after falling drastically.

Inspired by Dr. David Archer's simple and elegant climate models, I made a simulation to see how this entire story plays out. In a nutshell, I wanted to find how the temperature, and consequently, the ice cover on the Earth change as the solar constant gradually decreases; and in addition, as the solar constant gradually increases, how does the temperature and ice cover change. Clearly from the ice-albedo feedback cycle, this temperature will not stabilise immediately. We'd expect that for each value of solar constant, the planet would run into an ice-albedo feedback cycle, slowly stabilising its surface temperature. So, we also want to see how successive feedback cycles lead to a stable planetary surface temperature for each intermediate value of the solar constant.

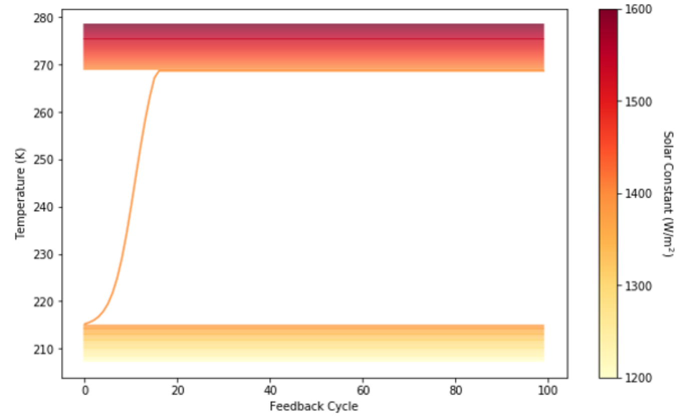

Figure 3: Stabilization of Planetary Surface Temperature over several ice-albedo feedback cycles for **increasing** solar constants. Solar constant ≈ 1400 W/m^2 acts like a cut off value for which the temperature stabilizes only after rising drastically

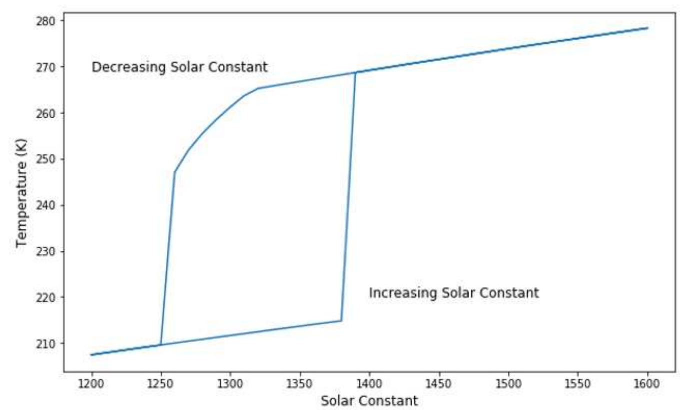

Figure 4: Hysteresis shown by stabilized planetary surface temperature with variation in the solar constant. The cut-off solar constant for causing an ice age is lower than the one required to reverse the ice age.

There are three major takeaways from Figures 2 and 3. Firstly, even though the solar constant changes gradually, the temperature, beyond a certain cut-off solar constant, changes very rapidly. This rapid change is due to a runaway effect of the ice-albedo feedback cycle. In Figure 3, since the solar constant is increasing, what we observe is the reverse ice-albedo feedback cycle, wherein, increased temperatures lead to melting of snow and therefore decreased albedo, which causes further increase in temperatures and so on. Either way, in both the cases, if the lower temperatures are referred to as an Ice Age (which they probably will be, as we're looking at a temperature of -63°C), we can see that the *Earth will fall in and come out of an ice age quite rapidly*, regardless of how long it is in the ice age.

Secondly, compare the rapid temperature change in the two cases. For a decreasing solar constant, the rapid temperature change is only about 35-40 K. For an increasing solar constant, the rapid temperature change is nearly 55 K. In other words, while falling in and coming out of an ice age is, in general, a rapid process, *coming out of an ice age tends to be more rapid than falling into one.*

Thirdly, the 'cut-off' solar constants in the increasing and decreasing cases are vastly different. This means the following: Suppose the Earth enters an ice age if it receives anything less than X units of power. Now, when the incident power has reached its minimum and is back on its way to gradually increase, this time the Earth will require a lot more incident power than X to bring it out of an Ice Age. Well it makes sense, right? An Ice Age Earth is significantly covered in snow. This means that the albedo of an ice age Earth is high. Therefore, with this increased albedo, most of the solar constant is simply reflected away. Thus, we'd need a much higher solar constant to compensate for the reflected power to successfully increase the planet's temperatures. Figure 4 illustrates this beautifully in the form of a hysteresis loop.

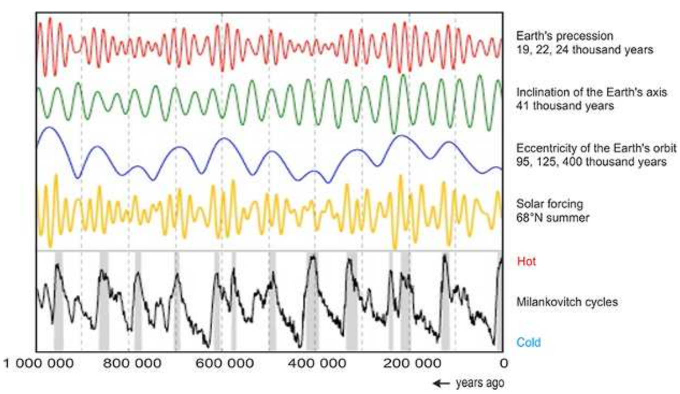

Figure 5: The Milankovitch cycles with the Earth's surface temperatures indicating glacial and inter-glacial periods for the past 1,000,000 years.

Now that we have a general idea of how average surface temperatures on Earth respond to the changes in the Solar Constant, let's try and look at the long term cyclic behavior of surface temperatures with the Milankovitch cycles.

Note that in Figure 5, the arrow of time runs from left to right. The bottom plot denotes the Earth's historical surface temperatures as determined through ice drilling experiments in the Vostok Ice core, Antarctica. Note how each maximum and minimum are steep peaks, indicating that indeed, the Earth falls into a glacial period (popsicle) and comes out of it rapidly. In fact, it also tells us that the planet doesn't stay at either of the extreme temperatures for very long. The upward peaks are periods of hottest temperatures. We can see that after each inverted peak (glacial period), the transition into an upward peak is almost a vertical line. Conversely, the transition from an upward peak (hot period) into an inverted peak (glaciation) is relatively gradual. This confirms our simulation's result that the Earth comes out of an ice age much faster than it falls into one.

NOTE: The simulation used to produce Figures 2, 3, 4, and the animation has borrowed Dr. David Archer's climate models from a class on Global Warming. The parameters used to perform the simulation, though not actual measured data, are meant to closely replicate real-life behaviour of the system under study. These include the range of solar constants, the relations between surface temperature, albedo and ice cover (latitude) in the iterative model, and the parameters of the Stefan-Boltzmann Law.

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Rats Running in a Physics Journal

Yajushi Khurana, *3rd Year B.Sc (Hons.) Physics*

Rats are infamous for the diseases they spread. However, ask any biologist – rats are still one of their favourite animals. Rats along with other rodents have been used for several immunology, neuroscience, and biochemistry experiments because of their chromosome numbers being very close to that of humans, and because of the ease of handling them that comes with their sizes.

In NCBS a group of Ph.D. students were working on open field data of rats (i.e. x- and y-coordinates of rats in a square field). The rats belonged to three different sets: a control group, a group with chronically induced stress (for 2 hours each day for 10 days), and a Nlgn-3 knockout group (mutations of Nlgn-3 have been linked with autism[1]). In earlier literature, it was shown that rats and mice show certain preferences in their exploratory behaviour (Maubourguet et al.[2]). They either display hyperactivity or hypoactivity. Similarly, they also prefer either centre or periphery when allowed to move around in an open field experiment. Instead of just analysing the exploration method based on the above two categories, these categories can be merged to form four states: periphery active, periphery inactive, centre active, and centre inactive.

The open fields were then divided into a central square that was called the centre and whatever lay outside was called the periphery (Figure 2). To decide the state of activity of the rat, a certain threshold speed was used. All speeds above the threshold were called active and all speeds below were called inactive. Several of these area and velocity threshold parameters were explored and the ones which showed maximum separation between the control and two different populations were chosen as the final distinction values.

Markov chains help us find the transition probability that the organism will move from one state to another. These transitions can be first-order, i.e. they can be dependent only on the previous state. For example, let's say the weather of some city can either be 'Rainy' or 'Sunny'. We can find the probability of the weather on a day by tossing a fair coin, and say each of them has a probability of half.

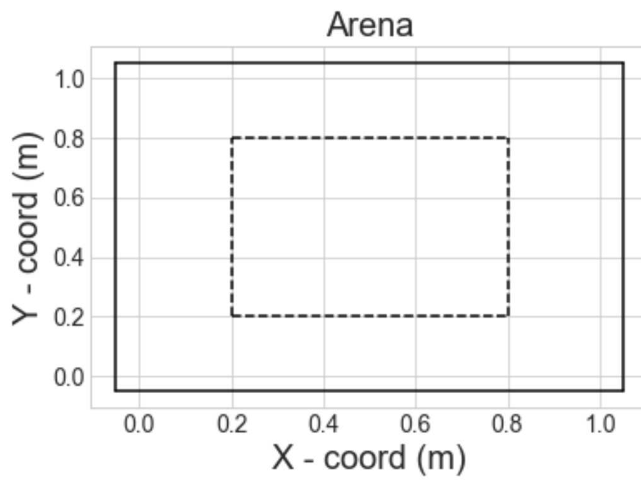

Figure 2: The centre is the region within the dashed box, and the peripheral region lies between the dashed box and the solid box.

But if we look closely we can see that if the weather is rainy one day, there are more chances of it being rainy the next day too and lesser chances for it to be sunny! Similarly with a sunny day! Therefore, we can say that instead of it being like a fair coin toss, the weather on a day also depends on the weather a day before.

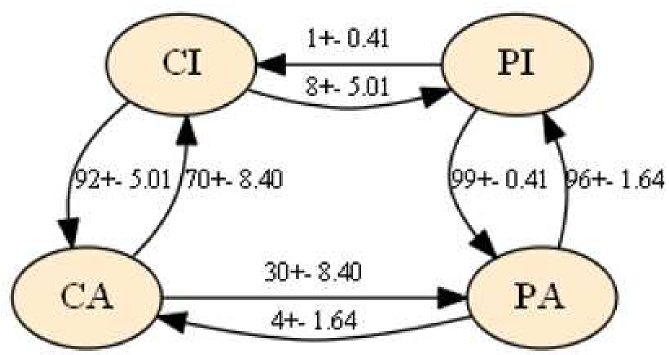

Figure 3: The average transition probabilities for stressed rats.

Variable length Markov chains are higher-order Markov chains, where the previous state is not only dependent on the state right before but also on states

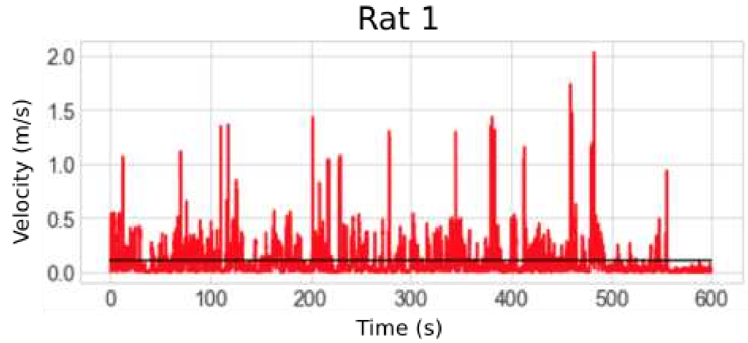

Figure 1: The solid black line shows the threshold velocity – all velocites above this threshold are considered "active", while all those below the threshold are considered "inactive".

before that. Just like in the case of the weather, if we say that for the last two days it has been rainy, there are more chances of the next day also being a rainy day! In cases where the order of a Markov chain is more than one, it is called a variable-length Markov chain.

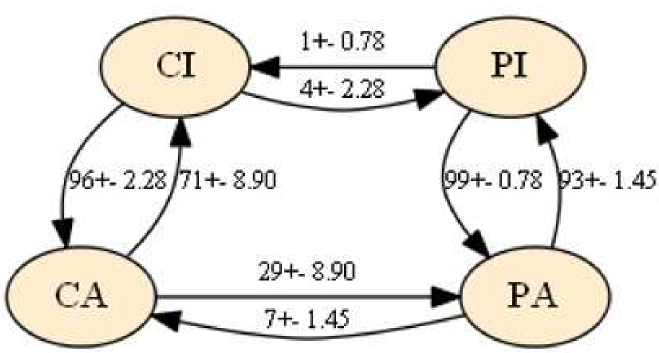

Figure 4: The average transition probabilities for control rats.

In the stressed vs. control case, the speed threshold came out to be 10.5 cm/s. Similarly, the ratio of the central area to the total area of the arena used in our analysis was found to be 0.5184 m^2. The central and peripheral regions were then marked in the arena. Every speed higher than the threshold was active and the rest were categorised as inactive. These arrays of activity and inactivity were matched to their spatial co-ordinates and finally segregated into centre inactive (CI), centre active (CA), periphery inactive (PI), and periphery active (PA). The transitioning probabilities were calculated for six different rats and then averaged.

A similar probability analysis was done by breaking the PA state into PAp (PA preceded by PI) and PAc (PA preceded by CA). Using this, second-order probability transitions were found when the rat moved from PAp to CI and PAc to PI as both the PA states were already preceded by a specific state.

It was be observed that the difference in the stressed and control transitions was more than the percentage error in the case of the rat moving from PA to PI and from PA to CA. Looking at the same transitions in the second-order model, the difference between the stressed and control transitions were more than the percentage error in case of the rat moving from PAc to PI than PAp to PI, which might show that the stressed rat transits more from CA to PA and then to PI than from PI to PA and then back to PI.

On increasing the sample size and checking it for significant results, more can be said about these transitions and if they hold any physical significance in quantifying some form of anxiety, fear, or major locomotive decision making of the rat. Similarly, the difference between the stressed and control transitions was more than the percentage error in case of the rat moving from PAc to CA than PAp to CA, which might show that the stressed rat transits less from CI to PA and then to CA than PI to PA then to CA. (The difference was negative. Therefore, the opposite conclusion has been made in this case. The values given in the table are all absolute values.)

For knockout rats, similar analysis did not show any trends. This could be because the knockout rats used in this field test were already habituated to a similar field in a previous test. Due to even lighting and no anxiety-inducing variable, it could have been possible that both the populations did not show any variability with respect to each other.

Transition	Error	Error Range (Stress)	Error Range (Control)
CI -> CA	4.20801	5.00785	2.28331
CI -> PI	4.20801	5.00785	2.28331
CA -> CI	1.19875	8.3964	8.90097
CA -> PA	1.19875	8.3964	8.90097
PA -> CA	2.89983	1.6352	1.44809
PA -> PI	2.89983	1.6352	1.44809
PI -> CI	0.0388692	0.411347	0.782579
PI -> PA	0.0388692	0.411347	0.782579

Transition	Error	Error Range (Stress)	Error Range (Control)
CI -> CA	4.20801	5.00785	2.28331
CI -> PI	4.20801	5.00785	2.28331
CA -> CI	1.19875	8.3964	8.90097
PI -> CI	0.0388692	0.411347	0.782579
CA -> PAc	1.19875	8.3964	8.90097
PAp -> CA	1.11778	0.905775	1.33297
PAp -> PI	1.11778	0.905775	1.33297
PI -> PAp	0.0388692	0.411347	0.782579
PAc -> PI	3.41412	1.84055	1.8756
PAc -> CA	3.41412	1.84055	1.8756

In the above two cases, Markov chains can help one look at the transition probabilities for first-order transitions and also for second-order transitions. These probabilities and the probability matrices can help one closely understand the behavior of the organism of interest. In case the organism shifts more to some state or reduces its movement into another state, it could tell us more about the activity and spatial location preference, which could help one clarify the locomotive and exploratory behavior of the organism.

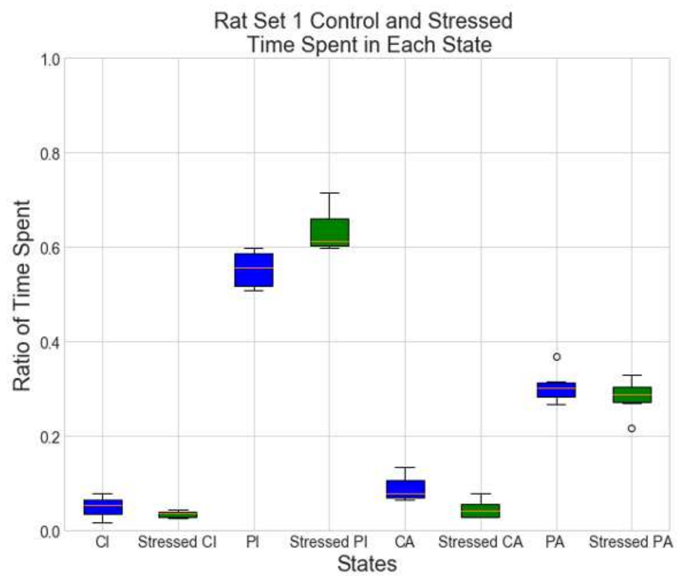

Figure 5: The average ratio of time spent in each state to the total duration of the rat's motion for stressed and control rats. The change in time spent in PI and CA was significant on the Wilcoxon test with a p value < 0.05. ($N = 6$, for control rats and $N = 6$, for stressed.)

Such studies that might not be directly related to physics can still have an important computational and mathematical component. I understand that rats are not so much fun for future physicists. However, in doing projects that are not directly related to physics one can understand more about other fields and alongside learn some interesting coding tricks that can help us later in our lives!

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Playing with Sensors

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Sensors are something that we use in everyday life. Smoke alarms and thermal scanners which can save countless lives and prevent damage to properties, accelerometers which are used to catch people who don't like staying within the speed limit, humidity sensors without which our daily weather reports would not be possible; the types and uses of sensors are numerous!

During the summer of 2019, the two of us went for a workshop to Miranda House, Delhi University, New Delhi. Our group decided to work with the Arduino UNO. The Arduino UNO, based on the Microchip ATmega328P microcontroller, is an open-source microcontroller board developed by Arduino.cc. It has a number of digital and analog pins which are used to make circuits. The expected behaviour of the circuit is then put in a code on the Arduino IDE and uploaded into the Arduino.

The aim of our project was to understand the workings of some basic sensors that we can see in daily life. We had worked on four types of sensors in our project: electrical conductivity meter, temperature sensor, water level indicator and metal detector.

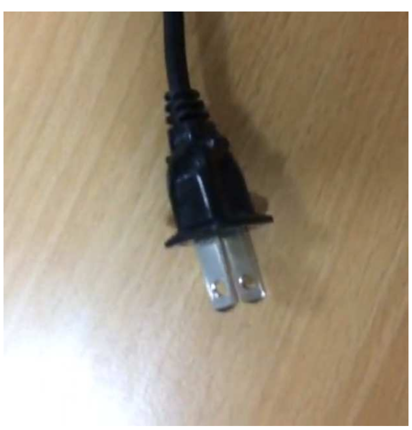


Figure 1: Electrical Conductivity Probe.

Electrical Conductivity Meter

The electrical conductivity (*EC* for short) meter can be used to determine the amount of impurities present in water. Electrical conductivity of a particular material is defined as the measure of the amount of electrical current that can flow through that material. In solids, electricity flows due to the presence of free electrons. In the case of liquids, electrical conductivity depends on the ion concentration in the liquid. These ions play the role of the charge carriers in liquids, similar to free electrons in solids.

Drinking water should ideally have an EC of $0.005 - 0.05$ S/m. Any value greater than that indicates ionic impurities.

Figure 2: Using the Electrical Conductivity Meter.

A two prong plug was used as the electrodes. It will be referred to as the probe from this point onwards. One of the prongs of the probe is given a voltage (i.e., it is the positive terminal) while the other is grounded (negative terminal). When the probe is dipped in water, the ions move in accordance to the polarity of each prong thereby setting up an electric current.

The current flowing through the circuit is of a known value and Arduino reads the potential difference between the two prongs. With this information, the combined resistance of the liquid is calculated using Ohm's law. The resistance of the liquid is calculated using the following formula:

$$R = \frac{V_{drop} \times R_1}{V_{in} - V_{drop}}$$

Here, R is the resistance of the liquid and the pin taken together, V_{drop} is the voltage drop between the two prongs and V_{in} is the original input voltage given to the circuit.

The resistance of the liquid, R_l is given by $R_l = R - R_a$, where R_a is the resistance of the pin. R_l is then used to calculate the electrical conductivity using the following formula:

$$EC = \frac{1000}{R_l \times K}$$

As mentioned above, EC stands for the electrical conductivity of the liquid for a particular temperature and K is the cell constant of the probe.

As the electrical conductivity changes with temperature, it is possible for a particular liquid to have the same electrical conductivity at two different temperatures. To avoid confusion, we calculate the electrical conductivity at room temperature, i.e., $25°C$. This is done using the following formula:

$$EC_{25} = \frac{EC}{1 + k \times (T - 25)}$$

Here, EC_{25} is the electrical conductivity for a given liquid at $25°C$, k is the temperature coefficient which changes based on the chemical (for our purpose, k is $0.019\ °C^{-1}$) and T is the temperature at which the measurements are done.

The EC meter also calculates the parts per million or ppm value of the ions present in the liquid. This is given by:

$$\text{ppm} = EC_{25} \times (c \times 1000)$$

Here, c is the ppm conversion coefficient. This value changes based on the system followed in a particular country.

Temperature Sensor

As was mentioned, the EC value depends on the temperature. So there is a need to measure the temperature of the liquid at the same time. For this, a temperature sensor was used.

Most physical phenomena are temperature dependent. To properly study the behaviour of materials, the value of the measured quantity (provided that the quantity in question is temperature dependent) is recorded only at a known temperature as it may have the same value at different temperatures for different sets of parameters. Thus, the readings become meaningless if independent variables like the temperature are not taken into consideration.

Figure 3: Temperature Sensor.

A PT100 temperature sensor was used to serve our purpose. PT100 sensor (Platinum resistance thermometer) is a temperature dependent resistor. PT signifies the fact that Platinum is used in the sensor and the number 100 signifies the value (of resistance in ohms) that it gives at $0°C$. Platinum is used in the sensor because it is more stable than the other temperature dependent resistors.

The relationship between temperature and resistance of Platinum is approximately linear for a small range. For a PT100 , a $1°C$ temperature change will cause a 0.384Ω change in the resistance. If we assume that the relationship between the temperature and resistance is linear over the range $0°C$ to $100°C$ then we will have a error of 0.4Ω at $50°C$.

The linearization equation is:

$$R_t = R_0 * (1 + A * t + B * t^2 + C * (t - 100) * t^3) \quad (1)$$

R_t is the resistance at temperature t, R_0 is the resistance at $0°C$, and:

$A = 3.9083 \times 10^{-3}$
$B = -5.775 \times 10^{-7}$
$C = -4.183 \times 10^{-12}$ (below $0°C$), or $C = 0$ (above $0°C$)

The acquired value of temperature was then plugged into the calculations for the EC through the Arduino IDE code.

All obtained values for the above quantities were printed on an LCD screen as well as the serial monitor which displays the output of the code.

Figure 4: Printing of Values on LCD Screen.

Water Level Indicator

We also built a water level detector using Arduino. As the name suggests, the detector is used as a signalling device to indicate that a container is filled up till its capacity.

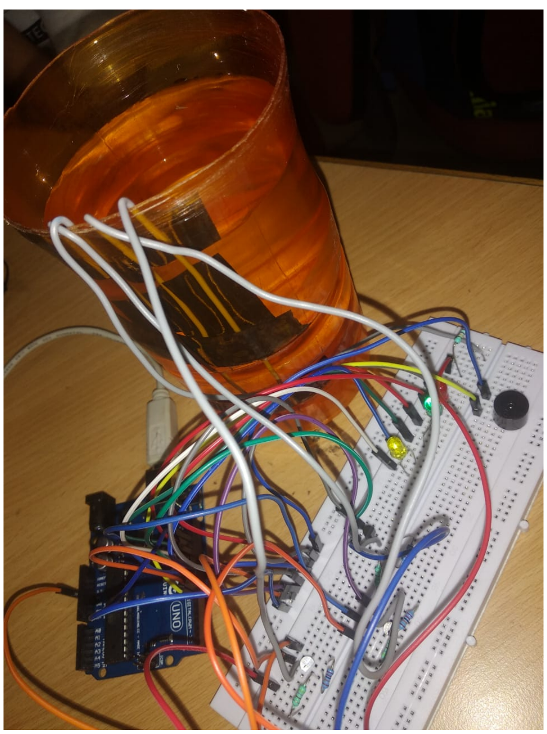


Figure 5: Water Level Indicator.

The working principle of the device involves the single very simple concept of conduction of electricity in a closed circuit. Here, the completion of the circuit is ensured as the water fills the container. Due to constraints we checked our electronic circuit in a very easily attainable plastic container. Wires were attached on the inside of the container till the bottom. Three LED pins of different colours indicated whether the water level was low, medium, or high. The level was also indicated on the serial monitor. Along with the LED pin, a buzzer also sounded to indicate when the container was filled to its brim.

Metal Detector

The final part of our project was the metal detector. A metal detector is used to detect both ferromagnetic and non-magnetic metals nearby. The working principle of the device involved the concept of electromagnetic induction. A changing current is sent through a single coil and this creates a changing magnetic field. Because of this changing magnetic field, a voltage develops in the coil in order to oppose the change in magnetic field. This process is called self-inductance.

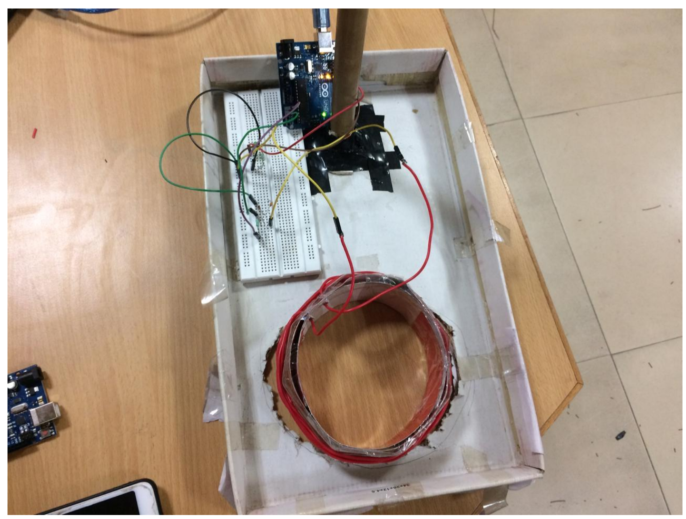


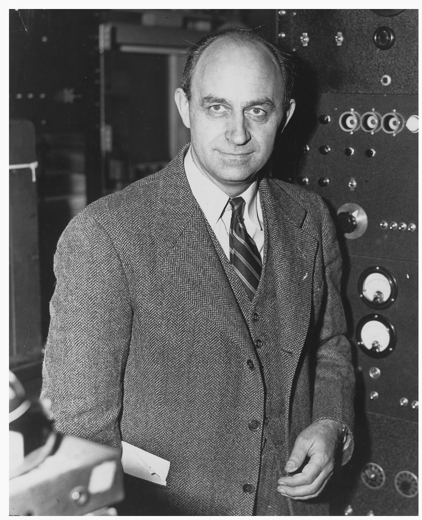
Figure 6: Metal Detector.

Due to the presence of metals nearby the self-inductance of the coil changes. This is so because when we move the detector over a non-magnetic metallic object such as copper there is an induced eddy current in the metallic object which produces a magnetic field which reduces the magnetic field of the coil. Hence, its self-inductance reduces. In the presence of ferromagnetic metals, the magnetic field of the coil is enhanced since the induced magnetic field aligns with the external magnetic field. Thus, in this case the self inductance of the coil increases. The measurement of the inductance of a coil can thus reveal the presence of metals nearby. With an Arduino, a capacitor, a diode and a resistor it is possible to measure the inductance of a coil: making the coil part of a high-pass LR filter and feeding this with a block-wave, short spikes will be created at every transition. The pulse length of these spikes is proportional to the inductance of the coil. These are difficult to measure directly. Instead, the rising pulse can be used to charge a capacitor, which can then be read out with the Arduino analog to digital converter (ADC). If the pulse is repeated a few times, the charge on the capacitor rises. The capacitor can then be quickly discharged by changing the readout pin to output and setting it to 0V for a few microseconds. This measurement is repeated and the average is taken.

The calibration of the measurement can be done automatically using software. If one can assume that most of the time there is no metal near the coil, a deviation from the average is a signal that metal has come close to the coil. Using different colours or different tones allows us to discriminate between a sudden increase and a sudden decrease in the inductance.

Enrico Fermi, and his Theory of Beta Decay

Oppenheimer had been among the first to introduce quantum mechanics to America and had founded a flourishing school of theoretical physics which produced many of the leading American theoreticians. He often presented physics in rather abstract terms which contrasted, at least in my mind, with the simple, direct approach to which Fermi had accustomed me. I remember a remark that Fermi made in 1940 at the time of his visit to Berkeley for the Hitchcock lecture. After attending a seminar given by one of Oppenheimer's pupils on Fermi's beta-ray theory, Fermi met me and said: 'Emilio, I am getting rusty and old, I cannot follow the highbrow theory developed by Oppenheimer's pupils anymore. I went to their seminar and was depressed by my inability to understand them. Only the last sentence cheered me up; it was: "And this is Fermi's theory of beta decay."'

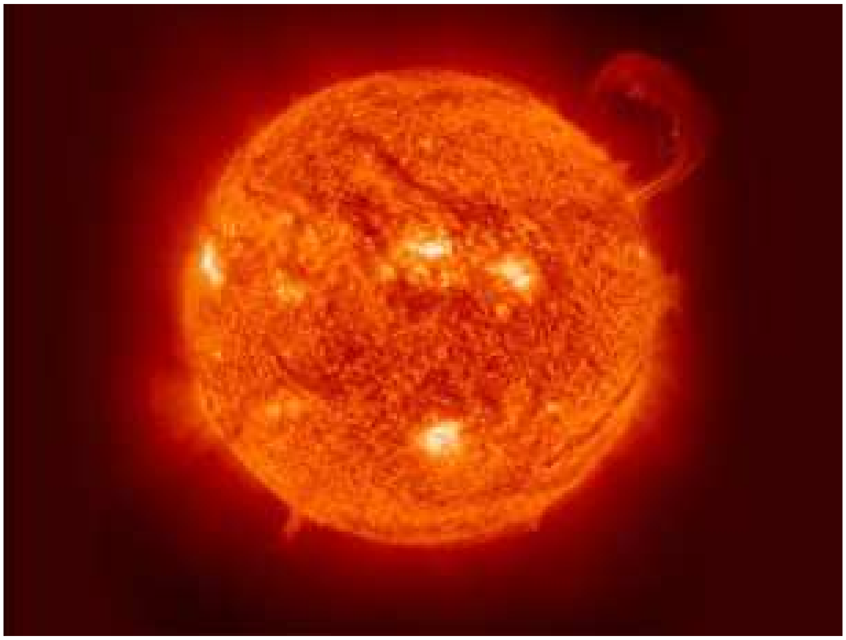


Enrico Fermi

From *Enrico Fermi Physicist* by Emilio Segre. *University of Chicago Press, 1970* p 134.

No Quantum Tunnelling, No Sun?

Anand Waghmare, *3rd Year B.Sc (Hons.) Physics*



This article was first published on www.medium.com and can be found here: https://medium.com/@anand.waghmare/no-quantum-tunneling-no-sun-b2c902393dbf.

Since 8^{th} grade, you must have been told that, "Sun doesn't burn but rather produces its energy by converting hydrogen into helium in its core through a process called Nuclear Fusion". While it is not false, it is not completely true either. Furthermore, you realise that to achieve nuclear fusion, ideally, it requires approximately 100 million degree Celsius (or, 100 million kelvin). However, what if someone came and told you another fact: The Sun's core has a temperature of approximately 15 million degree Celsius. What? Something does not fit the picture very well. If the Sun's core temperature is so much less than what is needed to bond protons together to make nuclear fusion possible, then what the 'hell' is happening inside the Sun?!

The answer is ***Quantum Tunnelling*** and no, I am not Nolan-ing you out.

To understand Quantum Tunnelling, we need to add a little bit of knowledge to our 10^{th} grade physics. Let's start with the concept of **total internal reflection**: when a light beam is passing through a denser medium to a rarer (less dense) medium, the beam refracts. Now, if you keep increasing the angle of incidence, there comes a point where no light is transmitted and, with a slight further increase in angle, the beam completely gets reflected back into the same medium, the critical angle.

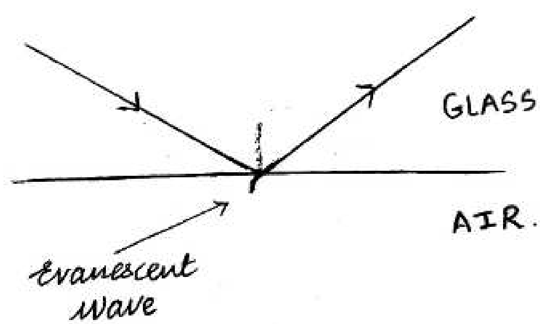


Figure 1: An evanescent wave.

Now, let's add a little bit of extra information here.

When we say that after the critical angle, the beam gets totally internally reflected and no light passes through, we overlook a very small part of the beam that does get transmitted. Yes! This part of the beam does get across the border into the next medium but dies off exponentially and, hence, this tiny tail is ignored. This is called the evanescent wave (Figure 1). Keep this term in mind simply as some kind of a property that the wave exhibits when bouncing off a surface.

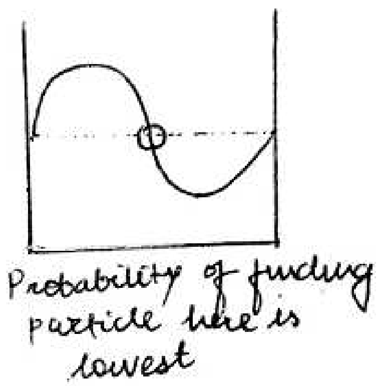


Figure 2

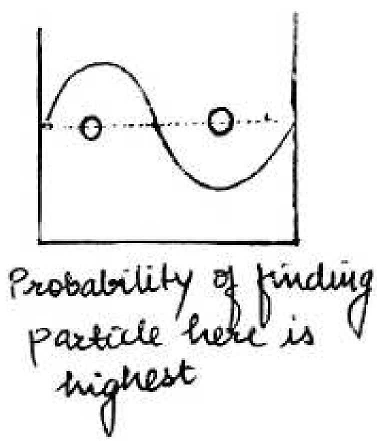


Figure 3

Now, we come to the Quantum world. Yeah! Generally, it is believed that small particles like photons, electrons and so on, behave like both a particle and a wave. This wave is not exactly the 'wave' we know of. It is a probabilistic wave. Let us look at this with help of an example:

Take the particle in a box – a very widely used example to understand the nature of the wave and quantum behaviour of a particle.

Consider in an empty box, a particle is let free but is restricted to move in only one dimension. Now, this particle can be anywhere on the straight line. But, at this scale, we cannot exactly point out the position of the particle at some given time due to Uncertainty Principle. There is one genius escape out of this!

Point by point, you go to find out the probability of finding the particle on that particular point. You take in all the probabilities for all these points and map it out in the form of a wave. It is this wave which physicists talks about in quantum mechanics!

Do you realise where we are heading? Remember when we talked about a wave bouncing off a surface, there is an evanescent wave. So, if the barrier is of a small width, the small tail can go across the barrier and be present on the other side too. The wave is nothing but a way of representing the probability of finding the particle there. So, even if only a very small part of the wave is crossing the barrier, it means there is some probability of finding the particle on the other side, which is outside the box (Figure 4). In simpler terms, even if the particle is completely enclosed in a box, there is some (however small it may be) probability that we can find that particle outside the box as well. In scientific jargon, this is called Quantum Tunnelling.

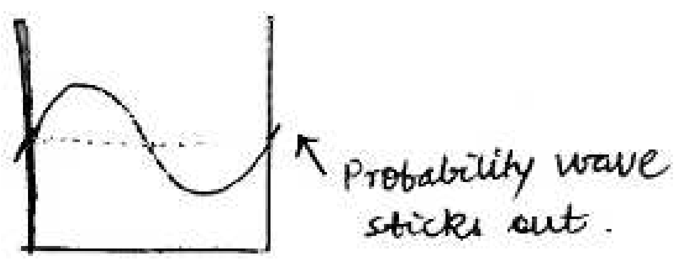


Figure 4: Quantum Tunnelling – when the probability wave sticks out of the boundaries of the box.

The box we are talking about is actually a potential barrier.

Coming back to the question of Nuclear Fusion. There are two major types of fusion cycles in stars. In lighter stars (like our sun) we have something called proton-proton (P-P) cycle and, in heavier stars, something called CNO cycle. However, the latter is not important right now. So, we will focus on the PP cycle. Like the name suggests, it involves the fusion of two protons. Now, the hydrogen atom does not directly get converted to helium. In the beginning, hydrogen atoms gets converted to their unstable isotopes, and, after a long chain of reactions, it settles to form helium (and several other by-products). This is fusion.

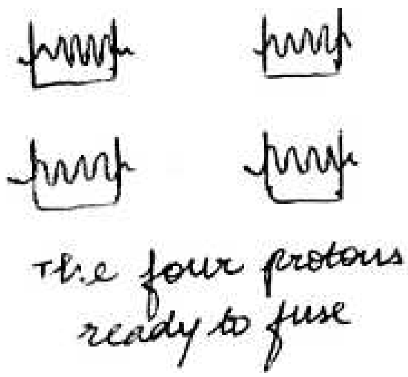


Figure 5: Nuclear fusion.

It is very difficult to bring two similar charges together and bond them over. But our understanding of quantum mechanics helps us overcome the confusion. Consider one proton to be a tiny probabilistic wave, bounded in a potential barrier. We know there is always a tiny tail of this wave that pokes through the barrier and hangs out. Thus, it is of immense ease for the proton to bond with another one through this tiny part sticking out. This is the reason for the reaction being possible in the Sun's core despite the core having lower temperature than required.

We need to keep in mind that the probability of quantum tunnelling occurring is in the order of 1 in 10^{28}. But there are so many particles present in the Sun that this reaction occurs on a very large scale and helps in fuelling the entire star. Sun's strong gravity pulls in these particles tight and thus creates favourable conditions for the fusion to occur.

So, this is it. We are done. But do remember that Quantum Tunnelling is very essential for the Sun to shine and for life to exist on Earth. Nolan-ed enough!

Noah's Flood: Go Forth and Multiply

And so it was to be, that after the waters receded, Noah commanded all the animals to "Go forth and multiply."

The ark quickly emptied, except for two small snakes, who stayed behind.

When Noah asked them why, they replied, "We can't multiply. We're adders."

Noah, being the resourceful man he was, immediately got busy cutting down trees and building a large table with the unfinished lumber therefrom.

And he saw that it was good.

The snakes were overjoyed when Noah picked them up and placed them on it. Noah and the snakes both knew that even adders could multiply on a log table.

From *Go Forth and Multiply*, https://crossposts.wordpress.com/.

2020: A Space Odyssey

Aninthitha Nath, *2nd Year B.A (Hons.) Political Science*

This article was originally written as an academic paper.

In a paper presented earlier this year at the American Association of Advancement of Science,[1] it was revealed that there would be an overwhelmingly positive response to the posited discovery of alien life. Humanity's fascination, and by extension, fear towards the very proposition of aliens has always been the forefront of discussion both in the scientific community and otherwise. This article, unlike some others in this journal will focus on a more of a social scientific perspective, examining the larger ramifications of a hypothetical encounter and justify humanity's reaction to the existence of intergalactic species. I am by no means staking a position on the outcome of the confrontation but on how we view this likely scenario within the confines of our pre-existing culture.

Institutes like SETI (Search for Extra-terrestrial Intelligence) are on the constant lookout for intelligent life in the stars and their discovery could soon become a reality, which is why it is important to gauge humanity's reaction to such a possibility which I argue to be negative.

Problematic pop culture narratives

Sci-Fi movies serve as a perception filter, serving the dual purpose of unequivocally "educating" the masses on theorised matters such as the discovery of aliens, and implants an inherent bias in the minds of those consuming this piece of media.

Considering how a majority of these movies, such as Alien, Independence Day, etc., have depicted aliens as an intergalactic plague, it is safe to assume that these prejudices are carried forward into our world through a highly impressionable audience. It carries forward a cultural significance in the growing popularity of science fiction, and an apprehensive reaction to the possible discovery of alien life in the years to come.

Pop culture narratives are problematic as they foster an inherent bias by stereotypical portrayal of both aliens and humans. It offers a simplistic view of intergalactic war as an exploitative fantasy. There is nothing beyond a vague fact of good and bad, us versus them. Our thinking of aliens is a proof of our imaginative poverty.

"Racial" Hostility

The first notable work on human-alien contact (which depicted an invasion of Martians) was H.G. Wells' *The War of the Worlds* which serves as a commentary on rabid British imperialism and Victorian prejudices. This brings us to the second part of this article: the arbitrary divides in society based on factors such as race, caste, gender etc. highly influence humanity's decision as a whole.

A negative reaction to such discoveries is hardly surprising when communities on earth are intolerant of each other's customs and traditions. Endless spells of hostility against a specific community: segregation in the United States, and the lynching of Dalits in "traditional" Indian society for example, have persisted throughout time and are now threatened to persist through space. Cultural, linguistic, and physical differences among others are the leading causes for blatant discrimination, and not to forget Elon Musk's recent and deliberate endeavours to colonize space – societal biases carry forward into scientific behaviour, no matter how fervently we try to deny it.

The underlying reason is fear, and as our biases precede us, retaliation in the name of fear will be humanity's first line of defence in a battle they made up for themselves. In his 1987 speech to the United Nations General Assembly, the then American president Ronald Reagan said, "I occasionally think how quickly our differences worldwide would vanish if we were facing an alien threat from outside this world." This propagandised fear uniting a highly prejudiced species is worth a note and a willingness to put aside personal differences to protect self against a bigger foe is a key aspect in invasion literature and focuses on the effect of new knowledge on the human psyche.

Larger philosophical themes

The hypothesized existence of aliens implies that humans are not the sole creators of value. Love, emotion, order, nostalgia, etc. are not exclusive to our species and may very well differ due to cultural (and linguistic) differences.

Turning this status quo upside down with the arrival of interstellar travellers would be a shock, and not be received well, as it is in our very nature to centre things around ourselves. Earthly beings have lived in galactic isolation for so long that any actual sign of whether life may exist outside our planet, will certainly send it into a frenzy. Look at Galileo for instance, who was convicted of heresy for daring to corroborate the fact the earth did indeed revolve around the sun. This happened a little short of 400 years ago, but the conservatism of humankind still permeates society. Humanity has always been incapable in the idea of expanding self, which leads to the short-sighted narrative presented at the American Association of Advancement of Science.

Our system of approach was created by us and for ourselves and leaves us incapable of the mental coherence to even try and interact on a rational level with other worldly beings.

Even if an ancient and advanced extra-terrestrial civilization wished to help humanity, humans could suffer from a loss of identity and confidence due to the technological and cultural prowess of the extra-terrestrial civilization.

Such philosophical questions are not expanded upon in the initial paper, neglecting the cultural impact that even a rudimentary galactic organism could have on our understanding of the value system, and our enforcement of it across the known universe.

Humanity's inherent fascination with aliens is a way of projecting our fantasies into a different narrative; holding a mirror unto ourselves. At the current psychological state of the world, humanity would NOT be welcoming of aliens as illustrated by pop culture's perception filters, fostered cultural biases, and an incapability to broaden our scope of interaction with an intergalactic species.

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Happenings in the Physics Society

Risham Parmar, *2nd Year B.Sc (Hons.) Physics*, Secretary of the Physics Society (2019-2020)

The Physics Society of Ashoka has been actively involved on campus since its conception in 2018 with the physics students of the undergraduate batch of 2020. We aspire to build a stronger, more inclusive scientific community in Ashoka.

In the Physics Society, our weekly Friday night screenings are about anything and everything from the validity of flat earther and ancient alien claims, to documentaries about finding the Higgs Boson. The discussions often focus on individual arguments and healthy debate.

Student talks are a Physics Society initiative for students to share their ideas and understanding of topics. We have had talks about the science of the superhero, Flash and the Voyager Golden Record. There have been three talks about astronomy: about the folklore surrounding constellations, basics of stargazing and a session with the telescope. We also had a talk about rockets and how they work. An expert was invited for an interactive Q & A session on aviation.

Mixers are organised to welcome physics students into the society and build a community to help each other out.

The open lab and demonstrations are an important part of our goal to make the sciences a part of the Ashokan Environment. These are often basic, easy to do experiments done outside the labs to bring the department into the public space and merge with the entire campus.

Our aim with our events is to create a scientific community at Ashoka. We try to make sure that all our events are accessible to and interesting for a majority of people from all academic backgrounds.

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Semesterly Visits to Research Institutions

Risham Parmar, *2nd Year B.Sc (Hons.) Physics*, **Riya Banerjee**, *3rd Year B.Sc (Hons.) Physics*, **Yajushi Khurana**, *3rd Year B.Sc (Hons.) Physics*

Inter-University Accelerator Center
Monsoon Semester 2019
Date of Visit: 6th September 2019

Last semester, a group of second and third years, accompanied by TFs, visited the Inter-University Accelerator Center in New Delhi to learn more about the research conducted there. The visit started with a presentation which was about the application of particle accelerators in various seemingly unrelated industries, with a particular focus on its use in the field of medicine. We felt that this was a nice way to start off given that we tend to only understand physics, in theory, not fully knowing of its practical applications, especially in fields that are not necessarily physics-oriented. We were then shown, some physically and some in diagram, various accelerators and scientific facilities used for research there. These included the Pelletron (we could not see this in person but were explained the working through a diagram), Pelletron Accelerator RBS-AMS Systems (PARAS) and the Low Energy Ion Beam Facility (LEIBF) among others. We were given detailed explanations about the working of each and the guides also made sure that, whenever possible, they would connect what they were explaining to courses we had taken in previous semesters. Overall, we felt that this trip was a worthwhile experience and gave us a kind of understanding which isn't possible in a classroom lecture.

Figure 1: Inter-University Accelerator Center

India Meteorological Department
Spring Semester 2020
Date of Visit: 24th February 2020

A group of first, second and third-year Physics majors along with a group of TFs visited the India Meteorological Department, Lodhi Road, Delhi to learn and understand the scientific research conducted at the institute. The staff members at IMD gave us a tour of various facilities like Central Hydrometry Observatory (CHO), National Centre for Satellite Meteorology, National Weather Forecasting Centre (NWFC) and their Air Quality Index measuring unit. We were shown around the facility and the instruments used to record temperature and measure rainfall level at CHO, followed by a detailed tour of the lab and instrumentation used by IMD to measure the PM 2.5, PM 10 and ozone in the atmosphere. After this, we were taken to the National Centre for Satellite Meteorology and shown how satellite data was collected and processed in various forms. At NWFC, we were shown how the above-mentioned data was used in forecasting weather locally and globally. This was followed by lunch after which we returned to campus.

The instruments used for data collection included older as well as more advanced instruments. It was interesting to note that older instruments, such as the one used for finding ozone in the atmosphere, are still used as a standard and are extremely accurate. This takes away from the general convention that “new is much better” in a very relevant sense. This visit helped us understand various forecasting methods, instruments, and working of these different centers. Additionally, we also got a chance to interact with several scientists who have been working at this institute about all scientific and computational tools required to produce and comprehend weather forecasting data. It gave us an opportunity to look beyond our classroom learning and helped us understand the applications of the physics we learn in our curriculum.

Figure 2: India Meteorological Department

We would like to thank the Ashoka University Physics Department for sponsoring these excursions.

The Physicist and the Horseshoe

A physicist had a horseshoe hanging on the door of his laboratory. His colleagues were surprised and asked whether he believed that it would bring luck to his experiments. He answered: ‘No, I don’t believe in superstitions. But I have been told that it works even if you don’t believe in it.’

Told by I B Cohen, the Harvard historian of physics, to S A Goudsmit who told it to Niels Bohr, whose favourite story it became.

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Astro Club
Ashoka University

Our telescope, Zoom, in Almora (2019)

The Astronomy Club was formed back in 2018 by just a couple of astronomy enthusiasts, when the Physics Department first bought our telescope, *Zoom*. From then to now, with new batches of students coming in every year, the Astro Club is growing into a vibrant body of budding amateur astronomers! While a significant fraction of the Astro Club membership comprises of Physics majors, there are also multiple students from other diverse academic backgrounds who are interested in the affairs of the stars. Here, we provide a glimpse into the recent activities and our future vision for the club.

One of the most beloved possessions of the Astro Club is our 8” Newtonian Reflector Telescope that we have endearingly named Zoom. Zoom can generally be found hangin’ out in the first-floor physics lab or the science block terrace (when it isn’t busy searching the skies!). When in use, Zoom is mounted over an equatorial tripod making it a suitable setup for tracking purposes and astrophotography. On clear nights, the Astro Club sets up Zoom between the residence halls attracting a decent sized crowd (that is generally unsuspectingly returning from dinner!). We have used Zoom on campus to observe various astronomical bodies ranging from our neighbourhood – Saturn, the moons of Jupiter, the craters on the Moon – all the way to Messier catalogue objects like Pleiades, the Orion Nebula, the Andromeda galaxy and other such elusive astronomical objects. Our activities with Zoom have been of paramount importance in our effort to create widespread interest in astronomy amongst the general student body. It is not rare to find Ashoka students standing on a small stool near Zoom and attempting to capture the craters on the Moon or the rings of Saturn using their phone’s camera.

The Moon, Ashoka (2019)

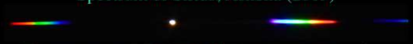
Ring Nebula, Almora (2019)

Saturn, Ashoka (2018)

The Orion Nebula, Almora (2019)

Star Trails, Almora (2018)

Spectrum of Sirius, Ashoka (2019)



Collimating the telescope, Ashoka (2020)

Last year, the Physics Department bought a diffraction grating for our telescope, which has allowed us to begin doing simple stellar spectroscopy. We have used Zoom to record the spectra of Vega and Sirius (amongst the brightest Type A stars in the northern night sky) and identify their Hydrogen Beta, Gamma and Delta absorption lines.

Occasionally, the telescope also requires collimation. Collimation is the process of adjusting the angle between the primary and secondary mirrors in order to minimize (and ideally eliminate) optical aberrations, and thus focus the light better to build clearer images of astronomical objects. To aid in the process of achieving good collimation, the Astro Club also recently invested in a Cheshire Collimator, which is an instrument that helps in aligning the telescope mirrors correctly.

By replacing the eyepiece of Zoom with a DSLR camera, the telescope has also been used for astrophotography. Aside from this, we have also performed unaided astrophotography with only a DSLR and a tripod by taking long-exposure shots of the sky that display clear star-trails.

The Astro Club has gone on two Astronomy trips so far, both to Almora, near Nainital. With skies as clear as we’d ever seen, we spotted absolutely gorgeous objects in the night sky – the Andromeda galaxy, the Hercules cluster (M13), the Crab and Ring nebulae, and several other elusive objects. We saw satellites tumbling across the sky, saw scores of shooting stars, and took some really pretty long-exposure images. The Astro Club plans to make these trips a yearly affair – after all, the really exciting astro stuff can only be done away from Sonipat skies!

Almora (2018)

Almora (2019)

Astro Club, 2019-2020

We have several activities planned for the upcoming year. We have procured the optics required to construct a refractor telescope. Once the campus re-opens, we will collectively assemble our second telescope. While the assembly would be supervised and performed by the club members, we intend to make it an open event so more people can learn about the basics of optics and telescopes during this process.

We intend to use this newly assembled compact refractor along with our solar filter to also start doing solar astronomy related activities such as observing sunspots or studying the solar spectra (with our diffraction grating). Because of its compact size, we also plan on carrying this refractor to nearby places and perform tailored public demonstrations and activities for a wider audience.

We also plan on doing stellar spectroscopy with greater professional sincerity in the coming months. This would include observational activities like recording and maintaining a bigger catalogue of stellar spectra. Furthermore, we also wish to engage in data-driven astronomy by writing programming models for the analysis of the recorded spectra and, later, using machine learning to automate this process.

This write-up was done jointly by Kartik Tiwari (1st Year B.Sc (Hons) Physics), member of Astro Club, and Rashmi Gottumukkala (3rd Year B.Sc (Hons) Physics), Head of Astro Club.

The Astro Club would like to thank Philip Cherian for all his guidance and enthusiasm, which has helped the club grow and flourish.

In Memory of Pluto
(An elegy to "Planet" Pluto)

Heer Shah, *3rd Year B.Sc (Hons.) Physics*

I

While Europe rejoiced
The cold wind that after a long time blew,
Some sat to question
Whether the planet be given a definition anew.

The outcome of this unwarranted discussion
Was all but a violent concussion,
And so the desire to invalidate the judgment in me grew.
But what could I possibly do?

Hence, I sit trapped
In the sultry labyrinth of monotony,
Unable to find a way to cope
With the worst debacle in the history of astronomy.

To this very day, I lament the relegation
Of your classification
From a Planet to a mere Dwarf Planet.
Oh, God dammit!

II

Forty Astronomical units from here
Lives an entity like none other:
It has only an occasional atmosphere,
And one-third of its surface is ice cover'd.
The discovery of this glowing body of ice and rock
Was the result of a three decade long space-hunt.
It quickly became every town's talk,
And the average Joe's conversation rut;
Nonetheless, only a select few understood
The significance of this magnanimous discovery.
It signified that man very well could
Transcend his own small bubble, an inane sanctuary.

In many a minds Pluto remains just another hype,
But I assure you that this idea is at best unripe.

III

What's in a name?
That may be the best or just plainly lame,
But anyhow doesn't change the bearer in any way.

So, even though you're not a planet anymore,
Nothing about you seems to be different from before.

What's in a name?
That one cannot for themselves frame.
All it shows is that you have been tamed.

So, don't mourn over the loss of a cosmic title,
Because to you, freedom is what this loss entitles.

What's in a name?
That is chosen with a bit of gambling, a kind of game.
On some other day the result wouldn't have been the same.

So, don't cry over something that has no value,
For it doesn't truly matter how I call you.

Indeed, there's nothing in a name,
That has little bearing on anything you can imagine –
It is this idea that brings me some solace.

The Strangest Man: A Book Review

Rashmi Gottumukkala, *3rd Year B.Sc (Hons.) Physics*

As we explore college physics, we are met with the familiar giants – Newton in classical mechanics and optics, Kepler in the study of planetary motion and central forces, Maxwell in the context of electromagnetism. In a way, the study of these people and their theories seem to very naturally follow from what we learnt in school, and they seem to be the natural course of progression from school-level simplicity to college-level complexity. But as we delve into our subject, we encounter giants of the sort that were never foreshadowed in school physics. Einstein of course is one of them. When we study special relativity in college, it is not just a study of the mathematics of it that allows us to understand the subject better. Understanding special relativity seems to require an internal struggle to come to terms with the theory. It's almost like striking a bargain with your intuition, and reassuring yourself that someday, sometime, lengths contracting and times dilating will perhaps seem less ridiculous than they do now. Dirac is another such giant – one whose physics is truly never foreshadowed, neither in school physics nor in popular science. And when we encounter his physics in college, we sort of begin to understand why. It's because his physics is so deeply mathematical, so difficult to intuitively grasp, that Dirac's physics stands on a pedestal of its own. Here, rather than striking a bargain with your intuition, it's more like telling it "Hey, we've had a good run so far, but now our time's up!". Perhaps one of the few things we *can* do to come to terms with Dirac's Quantum Mechanics is to understand Dirac the scientist in the context of Dirac the man. This is what Graham Farmelo's "The Strangest Man: The Hidden Life of Paul Dirac" attempts to do, and does so marvellously.

In "The Strangest Man", Graham Farmelo meticulously follows Dirac's life, from his early beginnings in Bristol, on to his illustrious life as a scientist of unparalleled genius, and then to his life as a family man. The book is very well researched, and goes into astonishing detail, given that very little is generally known of Dirac's personal life.

Dirac had a queer childhood. His parents came from simple backgrounds – his father, Charles Dirac, was the Head of Modern Languages at the local Merchant Venturers' School, and his mother, Flo Dirac, was a homemaker. The Dirac household was a strange place to be – Dirac had an overly doting mother, while his father was cold, strict, and distant. The family never entertained visitors, and as a result, the Dirac children had an almost non-existent social life.

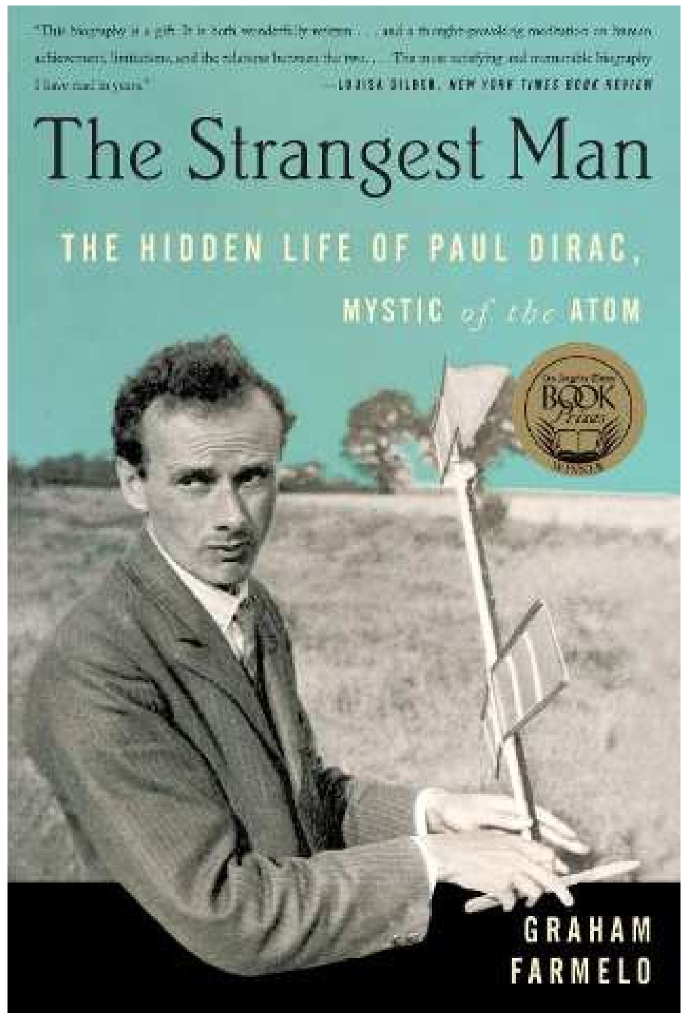


Figure 1: *The Strangest Man: The Hidden Life of Paul Dirac* was written by British physicist and author Graham Farmelo, and was first published in 2009 by *Faber and Faber*.

Dirac was a quiet child. Family dinners were terrible for Dirac, writes Farmelo, because he would be forced to eat alone with his father in the dining hall while his siblings and mother ate in the kitchen. His father would entertain conversation in French alone (his father was originally Swiss) and if Dirac stuttered, or stumbled in his speech, his father would deny Dirac's next request. Many years later, Dirac said that "[he] never knew love or affection when [he] was a child". Farmelo writes that this traumatic childhood experience might be what caused Dirac to be so introverted throughout his life and could have caused what some people speculate to be his autistic nature.

Early on, Dirac showed signs of mathematical adeptness. He came out at the top of his class in almost every subject he pursued in high-school, and this record continued into his bachelor studies in electrical engineering at Bristol University, although he never had much of a knack for practical subjects. Farmelo writes that Dirac used his free time in university to develop his mathematical skills, and it was here that he began studying Einstein's theory of relativity as a part of a philosophy of science course taught by Charlie Broad. Dirac discovered his aptitude and interest in abstract mathematics and theoretical physics, and his talent was recognised by his teachers in Bristol. With strong recommendation letters after his undergraduate studies in engineering, Dirac managed to find his way to Cambridge.

As we follow Dirac on his journey through university and on to his Cambridge career, Farmelo manages to balance the interplay between biographical writing and accounts of Dirac's scientific interests. This is a theme that runs throughout the book – between detailed biographical accounting, Farmelo delves into long passages of explaining Dirac's current scientific obsessions and devotes a lot of the book to giving scientific context to every stage of Dirac's life. This is especially true when he documents Dirac's early career as a scientist, because from all angles, it seems like Dirac's driving force in Cambridge was physics and physics alone, and that is all he would think about, day in and day out. That is, of course, apart from his famous Sunday walks, which he would use to clear his mind by spending hours in the Cambridge countryside.

It is this aspect of Farmelo's writing – the scientific context he gives to every stage of Dirac's life – that makes this book particularly interesting to read for students of science. Leading up to Dirac's discovery of quantum mechanics in Cambridge in the 1920s, the book allows us to understand the shear depth and breadth of Dirac's scientific study, as Farmelo delves into long descriptions of these ideas. We also get a better understanding of the nature of scientific discovery, and how it really isn't isolated study of a subject alone that leads to radical scientific thought. Farmelo describes how Dirac's engineering training helped him in forming an unconventional approach to solving problems, and how Dirac's interest in abstract mathematics, especially geometry, allowed him to visualise problems in a language that was alien to many of his colleagues, but yet one that allowed him to formulate theories of mathematical beauty. This idea of mathematical beauty came to be a central motivation in Dirac's scientific work, and was as close as Dirac would ever come to believing in god.

It is in Cambridge that Dirac forged friendships that would last his lifetime. Here, he met Peter Kapitza, a Soviet physicist and at the time a scientist at Cambridge. Dirac would attend the weekly meetings of the Kapitza club, and occasionally deliver talks there on his latest work. Farmelo describes the stimulating scientific environment at Cambridge as something that Dirac thrived in and juxtaposed it with his miserable family life back home in Bristol. Dirac very occasionally went back home, and even when he did, he did so out of a sense of duty alone. Farmelo goes into great detail of Dirac's Cambridge career, but all the while keeps in mind the larger question of Dirac's family life, which gives us a real sense of his personal context.

Dirac of course had an illustrious scientific career, which Farmelo meticulously documents. His genius was recognised at Cambridge, and with his discovery of Quantum Mechanics, he quickly rose to fame within the scientific community. He travelled extensively across Europe, meeting leading scientists in the field, and forging new and long-lasting friendships. It was in the household of Niels Bohr, writes Farmelo, that Dirac first saw the warmth and joy that a family life can bring – one so different from his own, growing up.

Dirac met his wife, Manci, when on a visit to the Institute of Advanced Study at Princeton, and thus began his life as a family man. After a short courtship, Dirac and Manci settled down in Cambridge. It is still a bit of a mystery as to how Dirac, a man almost devoid of emotion, could find a woman he could be happy with. But this happy chance of meeting Manci led to great fulfilment in his life. Farmelo yet again expertly manages to capture the emerging feelings of Dirac and understand his thoughts as he embarked on this new chapter in his life.

Throughout the book, Dirac's scientific career dominates the narrative. Farmelo manages to capture the evolving trajectory of Dirac's science, and Dirac's approach to scientific discovery. As time progressed, Dirac developed a strong sense that it should be mathematical beauty that drives scientific thought, and not necessarily results from experiments. He believed that a messy theory with positive experimental results was worse that a beautiful theory without experimental support. This became his guiding light in his scientific career, and he carried it with him all his life.

Through the course of the book, what was really wonderful was how Farmelo managed to delve into enormous detail about both Dirac's family life and scientific career, and yet could maintain narrative flow. This made "The Strangest Man" a very readable book. He also found a way to document Dirac's personal growth at every stage of his life, and explore how his circumstances shaped the man within. At the end of it, I really don't know whether this book helps us come to terms with Dirac's science. But it certainly does help us understand the man behind it, whose science has revolutionised life as we know it today.

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Dirac, and his Bra-Ket Notation

While he waited for the war to end, Dirac began work on another edition of his book. His main innovation this time was to introduce a new notation he had first invented shortly before the war broke out. This system of symbols enabled the formulae of quantum mechanics to be written with a special neatness and concision: just the sort of scheme that Dirac had learned to appreciate in Baker's tea parties.

The centrepiece of the notation was the symbol $\langle q|$ for a quantum state labelled q and the complementary $|q\rangle$; together they can be combined to form mathematical constructions such as $\langle q||q\rangle$, a bracket. With his rectilinear logic, Dirac named each part of the 'bracket' after its first and last three letters, *bra* and *ket*, new words that took several years to reach the dictionaries, leaving thousands of non-English-speaking physicists wondering why a mathematical symbol in quantum mechanics had been named after an item of lingerie. They were not the only ones to be flummoxed. A decade later, after an evening meal in St John's, Dirac was listening to dons reflecting on the pleasures of coining a new word, and, during a lull in the conversation, piped up with four words: 'I invented the bra.' There was not a flicker of a smile on his face. The dons looked at one another anxiously, only just managing to suppress a fit of giggling, and one of them asked him to elaborate. But he shook his head and returned to his habitual silence, leaving his colleagues mystified.

From *The Strangest Man* by Graham Farmelo. Published by *Basic Books, 2009* p 326-327.

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Final Instructions: A Short Story

Kartik Tiwari, *1st Year B.Sc (Hons.) Physics*

"Nothing – that is exactly what happened when humans finished executing the 'Final Instructions'. Or at least, this is what we believed for the first twenty-three days.

"To truly appreciate this discovery, let me set some historical context. After our universe was created, it took humanity 14 billion years to step foot on its home moon. In another 2 billion years, cold fusion became as obsolete as the abacus. Time travel became, not only possible, but a regular affair. The idea of a universal speed limit turned into an item in the glossary of historical terms. Black hole singularities became tourist destinations and supernovae mere batteries that powered our children's toys. Our civilisation, like an ignorant child in its mid-400s, thought that it had solved every problem that could be conceived. When human presence was marked on every moon, every planet and every star, one could say humanity was truly in its adolescence.

"In 16 billion years, after exploring every corner and every dimension, we realised that we were the only form of intelligent sentience in this universe and every atom in it was ours to play with. The last piece in the puzzle of our existence was supposed to be put in place when we finished following the 'Final Instructions'.

"Years of meticulous scientific advancements, theoretically predicted that our universe was manufactured with intent. The experimental evidence came in the form of messages that were embedded in our reality itself. These messages travelled through the spacetime continuum, since its very inception, in the forms of gravitational waves. For centuries, we believed that the stochastic gravitational signals coming from the edge of space were only noise, remnants produced by the spontaneous creation of all matter and energy. It was only a millennium later that we realised this 'noise' had a complex rhythmic pattern that repeated itself precisely every 7 million years. Following these signals helped us find the four beacons hidden in hyperspatial dimensions that kept transmitting them from the edge of our universe. Now, there was no doubt that these beacons were hidden in these places by our creators who patiently waited for us to become barely intelligent enough and find them.

"Discovering these colourless blobs that gently caressed the cradle of human civilisation while hiding within their own geometry, had presented the need for one last mega-machine that had to be built. Studying these beacons led to the discovery of the 18^{th} spatial dimension. This meant there was one more layer of reality in addition to the ones where we play our games. The scientific importance of this discovery was overshadowed by the public excitement ignited by the Astroarchaeologicalist's discovery that the four beacons were inter-connected via a beautiful geometric pattern in this new dimension. They, for the lack of a suitable word, wrapped our universe like a cocoon.

"I was certain that whatever our creators wanted to communicate was embedded within the mathematics of this extradimensional architecture. We brought together a team of all engineers, scientists, mathematicians and historians who had sector 11-0-2 access in the universal information repository. A group of 153 elite individuals, with state-of-the-art bioaugmentation and instantaneous access to the infinite collective knowledge of human civilisation, was enough to crack open any mystery as easily as our drives bore through neutron stars."

For a brief moment, the serious look on Hoffer's face turned into a proud smile. Philosophers across the galaxies all agreed that if pride was not an important emotion, humanity would have gotten rid of it by now. Interviewing Hoffer in the control room of the computer – that he designed – must have fuelled his already elevated sense of accomplishment.

Hoffer does not care if he is perceived as arrogant by the members. His popularity rating was off the charts anyway and everyone was certain that he would be the next governor of the union of galactic clusters. For me, the control room was merely a creative choice. What better location to shoot a documentary about humanity's adolescence than in front of the machine that distilled the 'Final Instructions' by decoding the beacon's architecture.

In Hoffer's defence, creating a computer that uses the eight-dimensional spin of every electron in the universe as a memory bubble is an impressive feat. Maybe, the most impressive one. But there was no alternative either. Studying the membrane that hugged our reality required a device that utilised the entire universe as its computing unit.

"Of course, 11-Hoffer. Would you like to explain to our past and future audience what happened after your team finished decoding the architecture?", said I, desperate to finish this interview.

"Well, it took the fastest computer in the universe... or should I say... it took the universe itself about 19 seconds to analyse the architecture. This should give our audience a sense of the computational complexity of the problem at hand. This was easily the longest any code had run for eons.

We discovered that within this framework were the knobs that decided our universal constants. This architecture laid down parameters that set how matter interacts with matter and how energy interacts with energy. In a sense, this framework could be thought of as the source code of our reality itself. Even more impressively, we found a set of instructions.

We believe this is naturally the next step in our evolution as a sentient species. We believe that these instructions were left by our creators so that we may one day walk out of our cradle, create with those who created us."

"That is an interesting conjecture 11-Hoffer", said I. This time with genuine fascination. "Are you pointing to a Cosmic Cycle of Creation? What might be the purpose of this cycle? Why create sentience at all?"

I could feel a sense of insecurity within Hoffer. I had turned on my retina augmentations to ensure he is not lying or exaggerating. His cognitive chemical balance was slightly thrown off. These were the physiological indicators of someone who is nervous. Uncharacteristic, to say the least, for the most important person in the universe. "Well if you put it that way, it sounds like I am a priest from the silicon ages. I do not know the purpose of creation. I am a scientist and I know that the purpose of science is not to find purpose in acts. We fiddle around with atoms until we find things that we cannot explain. And then, we explain them. The answers to your question can only be given to us by the creators. I am sure they would be as thrilled to meet us, their children, as we are to meet them."

It was about time that I asked the real question, the one every thinking arrangement of chemicals in the universe wanted an answer to.

"11-Hoffer, as every 70-year old in the galaxy knows, nothing really happened after we finished following the instructions. What do you have to say about that? Some people are already claiming that the machine was a grand surveillance device to tip the balance of power within the western galactic cluster. In fact, a couple sun-systems in the north have already started building and testing new weapons in case a conflict may arise" I asked, closely monitoring his physiological truth indicators.

"Ah young man, the capitalists want to capitalise everything. They have weapons, so they want buyers. The radicals want to rebel against everything. They have centrally uncensored thoughts. So, naturally, they want to conspire against the union.

"Although, I would completely disagree with the idea that, 'Nothing happened'. Cosmologists of all systems can tell you that the Cosmic Microwave Background Radiation has turned hotter by 7 Kelvins in the last 12 days. This is an unprecedented rapid surge in temperature. Additionally, even the most distant of galactic clusters have suddenly stopped showing their usual red-shifts. There are dozens of physical anomalies that our 'Complete Science' is now unable to explain. Physically speaking, these phenomena can only point to two things: either every settlement on the edge of the system is burning massive solar engines and moving towards the centre –"

"Which is an absurd claim" I interrupted before 11-Hoffer could talk further to the audience about a political conspiracy theory.

"Yes. It is obviously an absurd claim. Therefore, the only possible conclusion is that the universe is folding back on itself." Hoffer replied.

"That is equally absurd."

"It is absurd – but not equally. If you think about it, the universe folding onto itself is just another way of saying that the reality is growing back to its inception. We have not yet studied the effects of the 'Final Instructions' on the temporal dimension. However, I have strong reasons to propose that time is reversing itself. Since we now exist untouched by the constraints of time, we are experiencing a cosmic disconnect. I believe sooner or later; we would be pulled out of this universe while it turns into a seed and restarts itself all over again. This is where the architecture comes in. The source code not only regulates our reality but stores the genetic information to produce the next one."

This had to be the second craziest idea I had heard in my life. The top craziest idea was only a matter of minutes away.

"This is definitely an exciting avenue for further exploration. It is as if science has been born yet again. What do you think would be the effects of your team's discovery on the political spectrum of things? Is the galactic administration concerned that this discovery of your 'Cosmic Disconnect' may cause a sense of widespread panic amongst the members?"

"It is hard to predict the political repercussions. But I believe it is the fundamental purpose of science to pull you out of your cognitive comfort zones into territories of the unknown. It is the feature of discovery to..."

Before Hoffer could finish, lights in the room turned green and a notification popped up on the computer's massive display.

It simply said,

"New Potential Message Observed
Type: Gravitational Pulses
Source: Beacon 3* and Beacon 4*
Authorization Required for Decryption"

It felt surreal. I had to ask my augmentations to check my biochemistry and ensure that I was not hallucinating. I came to document humanity's history to preserve a part of its cocoon. Now, I was going to witness it turn into a butterfly.

"This might be it. Young man, do you realise that this message might be the invitation from our creators! Welcome notes as we leave our cradle and liberate ourselves from this reality. We thought we became Gods when we twisted thermodynamics to confuse entropy. We thought we became Gods when we folded the fabric of space like a piece of ancient silk. Today it is different. Today we do not *think* we are becoming Gods. We *are* Gods."

Hoffer's vitals were all over the place. That man was the physical manifestation of excitement. With almost a cracking voice, he said the words "11-Hoffer Authorization Check. Commence Decrypting."

This time, the device did not take seconds to compute. It was a much shorter message. In fact, enough words to count on my natural fingers.

Do not, however, mistake the short length of this message as its insignificance. Every sentient soul in the universe would agree that this was the most important string of letters that human civilisation had come across in its history.

Hoffer fainted. Any man of his age and ideology could not have possibly taken this shock differently.

"Scan Complete. Intelligent Life Not Found.
Purging Data and Restarting Simulation."

Hoffer believed that humans were Gods walking out of their cradle to learn from their creators. I believe we were a school of fish that swam close to its tank, stared out of the glass wall for too long and thought that we had seen everything.

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Science of Superheroes: The Flash

Rahul Menon, *3rd Year B.Sc (Hons.) Physics*

Almost all of us at some point in our lives have fantasized about having superpowers. When polling people about their superpower of choice, superspeed often finds itself near the top of the list. Something about hurtling down the street, a million miles an hour like a bat out of hell just appeals to us all. And in all of comic-lore there is probably no character or superhero more synonymous with speed than Barry Allen, the Flash. So, here, we are going to break down the science of the flash, the complications of manifesting his powers in our world and how the comics take a shot at explaining his enormous arsenal of abilities.

Let's start by bringing the scarlet speedster's incredible speed to our world. Would this be possible, could you or I become the flash? Well... no. Sorry to burst your bubble in case you were hoping to leave this article with the secret ingredients needed to kickstart your superhero career. Moving at the flash's speeds in real life would be dangerous and unfortunately impossible. Let's begin with energy. For someone of the flash's height and weight, running at even one-tenth the speed of light for 5 minutes, would burn approximately 170 million calories. To put that into perspective, before taking his 225 or so laps around the earth (the distance he would cover in these five minutes), Barry would have to scarf down more than half a million cheese burst pizzas or slurp down three hundred thousand strawberry milkshakes, which when you think about it, honestly doesn't sound so bad. But even if we manage to sign an endorsement deal with dominos and fund our enormous appetite, we have another hurdle. The main problem with super speed isn't really the speed (though we'll get back to that in a bit). We already can and do travel at incredible velocities: the astronauts up in the international space station are orbiting around us at a whopping 7 km/s. The problem is the 'super-acceleration' – for the flash to get to his jogging speed of 0.1 times the speed of light in say about 0.1 s, he would have to withstand 30 million g's of force. And to get him to that speed, his legs would have to exert a force of about 20 billion Newtons. Finally, assuming you could somehow get to this speed and survive the acceleration, we still have a problem. Unlike the space station above us, running here on earth means we would have to deal with the air around us. Just like a space shuttle re-entering the atmosphere, you would burn up as you run across the street. Unlike what many people think, this burning up isn't actually due to air friction but because of a process called adiabatic compression. Simply stated, since no heat will be allowed to escape from the air that you are compressing, the air particles wouldn't have time to get out of our way. Running at these speeds, we would tear apart the surrounding atmosphere atom by atom, destroying not only ourselves but everything within miles in an enormous atomic explosion. Not the most ideal scenario. The Flash gets around these problems with the help of a fictional inter-dimensional source of energy, the speed force. The speed force is an overly complicated comic book creation that I won't be able to properly explain in a short article such as this, but I will briefly explain it at the end.

So yeah, we can't achieve super speed in our reality, and actually without all the sci-fi you can't get anywhere near the speed of light. This is thanks to Einstein's theory of relativity. The Flash, however, has been known to work around this pesky problem with the help of the speed force if need be but he's also displayed an ability to work with it. The amount of scientific detail and thought that goes into the writing may surprise some people and a stellar example of the same comes from the 'Infinite Mass Punch'. This impressive ability was first established in the 1997 JLA #3, where Flash used it to dispatch another speedster, Zoom. To begin with, as the Flash chases after Zoom approaching light speed, relativistic effects start to take over. For those unfamiliar with Special Relativity, Einstein explained that when an object moves really fast compared to another object, it can physically contract, experience less time and effectively gain mass. Flash mentions that as he ran towards Zoom his vision seemed to blueshift, which is absolutely correct. As he ran after Zoom, the wavelengths of light that his eye encountered would seem to compress and appear on the blue end of the spectrum. More importantly for his punch, his fist's mass would increase to that of a white dwarf star ('White dwarf star punch' just doesn't have the same ring) due to its relativistic mass.

If that was a little too complicated, here's a quick run through of some interesting uses of the Flash's speed. His abilities aren't limited to the physical but, in fact, come with advanced cognitive abilities too and that's a very good thing. Normal human perception hasn't evolved to handle Flash-like velocities. The world around us would become necessarily and dangerously blurry and there is actually a real world example of this problem: the tiger beetle. The tiger beetles are the Flashs of the insect world; they can cover 125 body lengths in just a single second, which would be like a human running at around 770 km/hr. Evolving to these incredible speeds makes them ferocious and dangerous predators, but due to the limits of their visual prowess, the insects are functionally blind while moving. Thus, they are forced to stop and start continuously or else they miss their prey completely or just bump into obstacles. This has actually been addressed in the comics and the Flash has been known to be able to perceive events happening at the order of attoseconds. His synapses fire at an incredible speed, allowing him to store a ton of facts in mere seconds. In "The Flash" Vol. 3 #2, the Flash uses speed reading to save dozens of people. When an apartment building is hit by a shockwave, Barry races to the library where he quickly reads several books on architecture. He returns to the building, reconstructs it as it's falling, and saves the tenants inside. However, this tsunami of information is soon forgotten within a couple hours, since the brain can't store all the information from short term to long term memory. Nevertheless, a very useful ability for those last minute study sessions before an exam. Bart Allen, Barry's grandson was actually able to optimize the ability with the aid of his eidetic memory as he could speed read, learn and retain vast amounts of data. Another fun use of this ability is 'speed talking' where speedsters can converse in this pseudo-secret language that no one but another speedster can follow.

Super speed is an amazingly versatile superpower. If an object can go fast enough, and build up enough momentum (escape velocity), it can break the grip of gravity and shoot upward. The Flash can easily get enough momentum to race up and down buildings, as well as towers and falling debris. The Flash has 'defied gravity' on multiple occasions to climb walls in order to save people. His speed also allows him to run on water. A normal human being would have to run almost 99 feet per second in order to keep from sinking. That's three times as fast as Usain Bolt. The Flash can, of course, blow past that speed with ease, which allows him to zip across the waves like he's running on pavement. He can create wind funnels by rotating his arms very quickly and even create a vacuum by running in a circle really fast, creating the vacuum within the circle. He can also vibrate parts of his body at any frequency he likes, allowing him to destroy objects by vibrating against them at their resonant frequency, and even mask his own voice by changing the vibrations of his vocal chords. He has actually shown such impressive control over this ability that he has been able to become invisible, by vibrating in place extremely fast and even been able to create a 'speed-mirage' by running back and forth very fast. The Flash's speed up metabolism also gives him super healing, with his body able to replace damaged cells at an incredible rate, even healing completely broken bones in a matter of hours. This also means that he is immune to most forms of poisons and tranquilizers. Now going into exact details of this vast array of abilities will take a lot of time, but I do believe that a majority of them should be easy enough to understand. But before we wrap up this article as promised, a quick break down of the speed force.

The Speed Force is a cosmic force based around velocity and movement and one of the Seven Forces of the DC Universe. It is a field of energy that grants all speedsters their power. If you can siphon enough of it and control it properly, it basically allows you to break the laws of physics, without damaging yourself or the surrounding environment. It envelops the speedster (and whatever object or person they might be rushing from place to place) in a cocoon of protective energy and protects them from all the problems spoken about earlier. It allows them to move even faster than the speed of light, phase through objects, travel through time and just do a bunch of things that simply can't be explained by science. But that's what makes comic books so much fun: we find that bridge between the fictional world and our own, losing ourselves in this universe of superpowers and colorful characters.

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The Sneeze Distribution!

Rashmi Gottumukkala, *3^{rd} Year B.Sc (Hons.) Physics*

Have you ever realised that when you sneeze, you do so only a fixed number of times? Everybody has a number. Mine is two. I know someone who either only sneezes seven times in a row or doesn't sneeze at all!

I spent two months last summer interning at a neuroscience lab at NCBS in Bangalore. Amongst the many different things I did there, here's something I decided to start one lazy afternoon (that, just to clarify, was very much *not* a part of my internship): to test my hypothesis that *I either sneeze twice in a row, or do not sneeze at all*. The reason I was slightly doubtful about the truth of the statement was this – was it just that my mind registered it when I sneezed twice? Maybe it was sort of like a lightbulb going off every time I double-sneezed: "Hey, there was a double-sneeze again!". In other words, a confirmation bias. Perhaps it could be that I did single-sneeze quite often, but I just didn't realise it because of the normality of it.

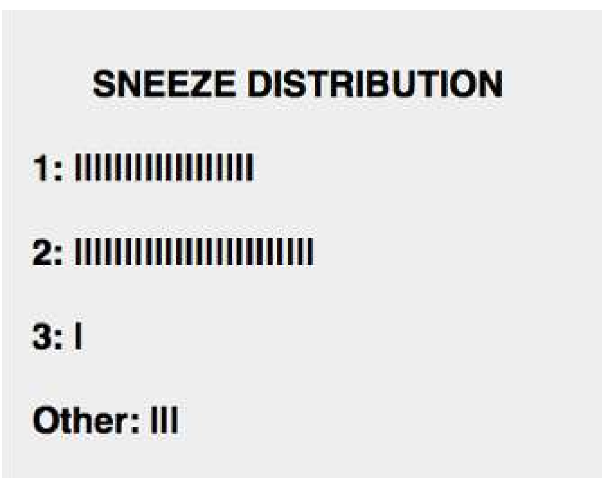

Figure 1

So, from May-July 2019, I recorded all my sneezes. You could say "Well, if your hypothesis is that you don't realise it when you sneeze only once, what's to guarantee that you will realise it now?" There is of course no guarantee. But I convinced myself that since I was sufficiently self-aware of my sneezes (given that I was doing the experiment), I would manage to record most of my sneezes. (And I also put some of my friends on duty, to catch me if I didn't record one!)

Here's how I went about it: I made three categories, as you can see in the table below: single sneezes (1), double sneezes (2), triple sneezes (3), and one bucket for all higher numbers. Every time I sneezed, I would add one bar to the relevant column in the table above. I kept a log of this table on my computer. The results of the table are shown in the histogram below, and they are really quite astonishing!

So, it turns out that while I do in fact double-sneeze most often, single sneezes aren't far behind! In the course of the two months, I double-sneezed 24 times and single-sneezed 18 times!

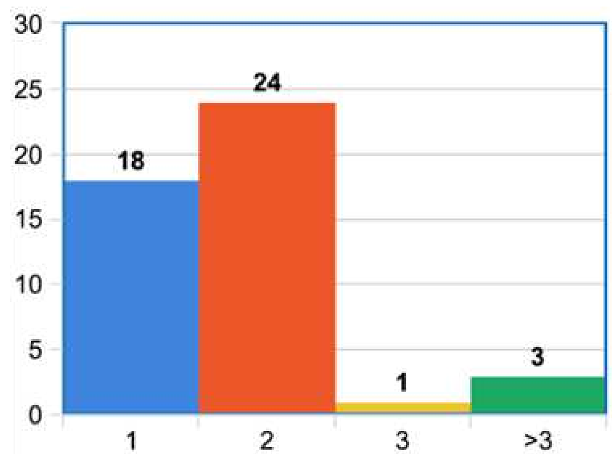

Figure 2

It seems then that this was the case all along, and that double-sneezing only registered with me because it became a "thing" for me to sneeze twice in a row. Confirmation bias indeed: the mind really does do strange things...

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How to be Friends with your Axes?

Yajushi Khurana, *3rd Year B.Sc (Hons.) Physics*

Do you remember your axes? Weren't you so close during your Mathematics classes in high school? But soon you started neglecting them, especially in your Physics lab reports. You forgot to introduce them with the right label in front of your friends and teachers. You even forgot to scale them and hurt their emotions and eventually broke up with them. I understand that you developed feelings for other concepts, but what would you do if you are still in a STEM field and you have to meet and greet your axes every time you try to look at things quantitatively and graphically? How do you keep your past emotions from spoiling your workspace relationships?

This is a short guide to help you understand the ill-effects of being on bad terms with your axes and how you can be friends with them.

Here are some examples of what it could mean if someone still hasn't resolved their past issues with their axes. *Morganti et al.*[1] published the following paper on "Electron transport chain complex II sustains high mitochondrial membrane potential in hematopoietic stem and progenitor cells" in the Stem Cell Research journal. The research mostly deals with the quantitative detection of certain biochemicals in the mitochondria. The following are some of the graphs for the results they obtained. For now, let's not be bothered what those results are but pay attention to the graphs.

If you noticed them, you would realise all the axes are a little baffling. Figure 1 is missing units on the x-axis and a label on the y-axis. Figure 2 has no units or axis labels for the x-axis. In Figure 3, two comparison graphs have different ranges for percentages on the y-axis. Several other graphs in the research paper were also missing units or labels (note that the figure legends also did not describe the labels or the units). Now, if going through the following paper was not 10 percent of my grade for one of my Biology courses, I would have possibly skipped this paper thinking that a paper that does not care about its axes is probably not so credible.

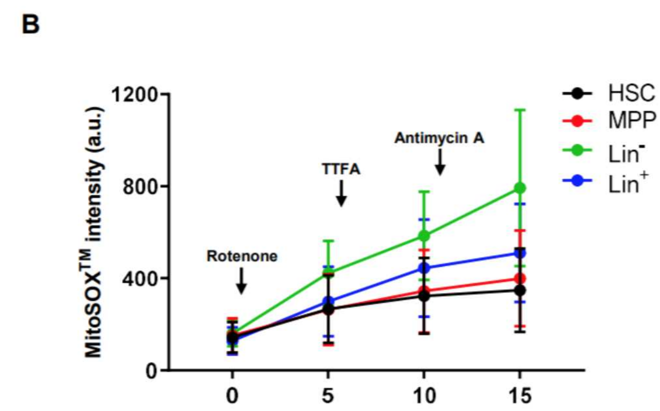


Figure 2

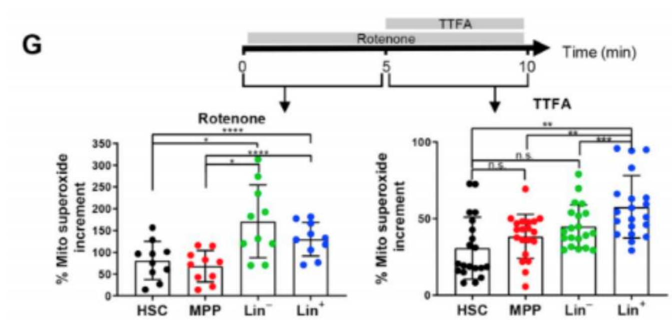


Figure 3

However, going through their work I realised they had decently investigated the subject. But imagine busy scientists and professors who come across your paper and notice that you haven?t looked after your axes. They might just skip your work even though it might actually be phenomenal. These scientists are looking for promising students to collaborate and build a relationship with. If they learn that you ignore your axes like that, why would they want to work with you or take you into their research institutes?

Worry not, before you start making these mistakes, learn from your well-wisher, and keep in mind the following points:

- Label your axes. Why not tell the world who

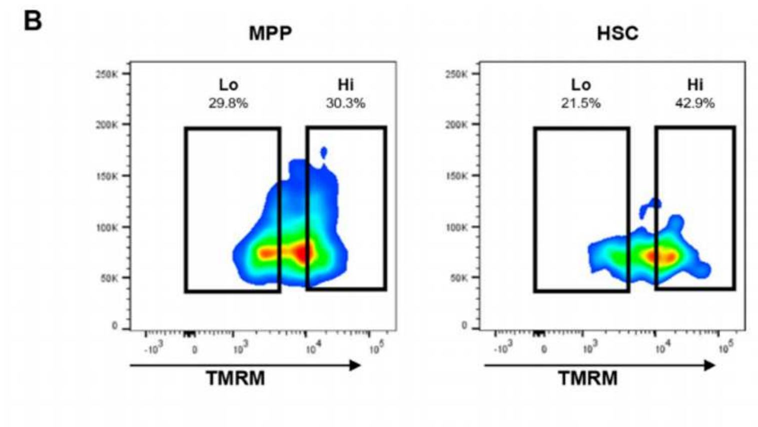


Figure 1

your axes are and what they mean to you? Your axes will appreciate it.

- Scaling your axes well can help regain their trust. Scale them carefully so that later they can help you present your data concisely. Going one step at a time if you have data points up to 10,000 is not optimal. Instead, take some leaps and get all your data points whilst keeping your axes short and happy.
- You have told the world who they are by labelling them. But wouldn't it be better if you also tell everyone how your axes like being valued and measured? Having the right measurement units next to them makes them feel special. I think that your axes deserve this!
- Your axes would feel even better if you showed some care for their legendary spouse: graph legends. Mark them and let your axes know that you want to keep the past behind and be friends with them and their beloved.
- Just remember to take care of all your axes. Discriminating between the x- or the y-axis isn't something you should try. For successful graphing, it's important that you keep both happy.

I hope that you keep these invaluable lessons in mind and give your axes the respect they deserve. Forget whatever happened in the past and take the abovementioned steps to look forward to a friendly relationship with your axes.

REFERENCES

[1] "Electron transport chain complex II sustains high mitochondrial membrane potential in hematopoietic stem and progenitor cells". Retrieved May 25, 2020, from https://www.sciencedirect.com/science/article/pii/S187350611930203X?via%3Dihub.

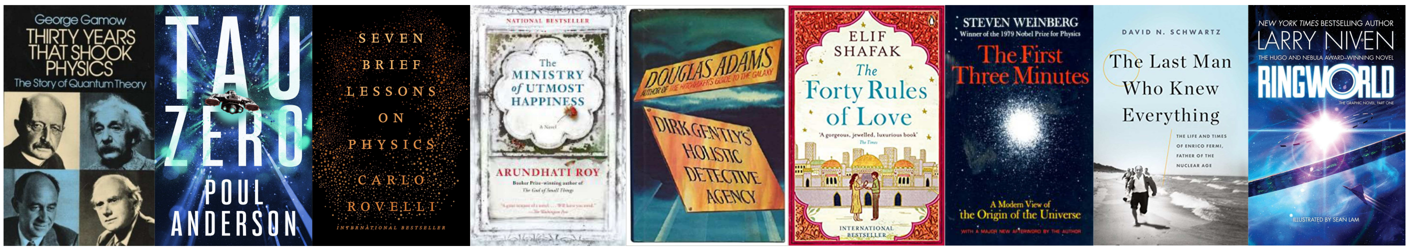
The Theorist

When a theoretical physicist is asked, let us say, to calculate the stability of an ordinary four-legged table he rapidly enough arrives at preliminary results which pertain to a one-legged table or a table with an infinite number of legs. He will spend the rest of his life unsuccessfully solving the ordinary problem of the table with an arbitrary, finite, number of legs.

From *Physicists continue to laugh*, translated from Russian by Mrs. Lorraine T Kapitanof. *MIR Publishing House, Moscow, 1968* p 134.

What's Better than a Good Book and a Cup of Tea?

We asked our professors and TFs to recommend books, films and documentaries for our readers. So below you will find a compilation of recommendations from our professors and TFs. For those of you movie buffs who think you've seen just about everything, perhaps this list will surprise you! For those of you who like to curl up with a good book and a cup of tea on a rainy day, we hope you find your way through interesting reads in this section! And for those of you who think reading just isn't for you, or for those who feel there's just no fun in a boring old documentary, perhaps this list might turn you around!



Book Recommendations

Thirty Years that Shook Physics *by* George Gamow (From Dr. S. Bhattacharya)
Here is an eminent theoretical physicist's retrospective view of the years between 1900 and 1930, which brought a drastic change in man's view of the universe. From Max Planck's momentous description of light quanta in 1900 to P.A.M. Dirac's 1929 prediction of anti-particles, it was a period of breath-taking progress in theoretical physics.

The Forty Rules of Love *by* Elif Shafak (From Dr. S. M. Bhattacharjee)
The Forty Rules of Love tells two mirroring tales in parallel: the quest of a housewife, Ella, who seeks out the mysterious author of the book *Sweet Blasphemy*, and the story of the thirteenth century poet, Rumi, and his spiritual teacher, Shams.

The Ministry of Utmost Happiness *by* Arundhati Roy (From Dr. S. M. Bhattacharjee)
The novel weaves together the stories of people navigating some of the darkest and most violent episodes of modern Indian history, from land reform that dispossessed poor farmers to the 2002 Godhra train burning and Kashmir insurgency.

The First Three Minutes *by* Steven Weinberg (From Dr. Bikram Phookun)
A work of non-fiction, Weinberg brings to the layman the science of the beginning of the universe. Weinberg gives the reader a basic understanding of astrophysics and particle physics, before delving into explaining *the first three minutes* of the universe.

Seven Brief Lessons on Physics *by* Carlo Rovelli (From Philip Cherian)
The book condenses the revelations of post-Newtonian physics – from Einstein's theory of relativity to quantum mechanics – into seven brief, accessible lessons.

Tau Zero *by* Poul Anderson (From Philip Cherian)

Tau Zero follows the crew of the starship Leonora Christine, a colonization vessel crewed by 25 men and 25 women aiming to reach the nearby star Beta Virginis. The text consists of narrative prose interspersed with paragraphs in which Anderson explains the scientific basis of relativity, time dilation, the ship's mechanics and details of the cosmos outside.

Ringworld *by* Larry Niven (From Philip Cherian)

Ringworld tells the story of Louis Wu and his companions on a mission to the Ringworld, a rotating wheel space station, an alien construct in space 186 million miles in diameter.

Dirk Gently's Holistic Detective Agency *by* Douglas Adams (From Philip Cherian)

Dirk Gently's Holistic Detective Agency is described by author Douglas Adams on its cover as a "thumping good detective-ghost-horror-who dunnit-time travel-romantic-musical-comedy-epic".

The Last Man Who Knew Everything *by* Andrew Robinson (From Ojasvi Khare)

A biographical work, *The Last Man Who Knew Everything: The Life and Times of Enrico Fermi, Father of the Nuclear Age* lays bare the enigmatic life of a colossus of twentieth century physics.

"The only thing that you absolutely have to know is the location of the library."

∼ Albert Einstein

Documentary & Film Recommendations

Cosmos (1980) (*Serial*) (From Dr. S. Bhattacharya)

One of the most widely watched series in the history of American public television, *Cosmos*, written by Carl Sagan and others, covers a wide range of scientific subjects, including the origin of life and a perspective of our place in the universe.

Ascent of Man (1973) (*Serial*) (From Dr. S. Bhattacharya)

Written and presented by British mathematician and historian of science Jacob Bronowski, over the series' thirteen episodes, Bronowski travelled around the world in order to trace the development of human society through its understanding of science.

Oppenheimer (1982) (*Miniseries*) (From Dr. S. Bhattacharya)

The miniseries depicteds Oppenheimer's wartime role as head of the weapons laboratory of the Manhattan Project, during which he was under constant surveillance by the federal government because of his association with Communists.

Powers of Ten (1968) (*Documentary*) (From Dr. Bikram Phookun)

This short documentary depicts the relative scale of the Universe according to an order of magnitude (or logarithmic scale) based on a factor of ten, first expanding out from the Earth until the entire universe is surveyed, then reducing inward until a single atom and its quarks are observed.

Contact (1997) (*Film*) (From Philip Cherian)

A film adaptation of Carl Sagan's novel of the same name, Dr. Ellie Arroway, guided into science and communication by her now-deceased father, listens to radio emissions from space, hoping to find evidence of alien life.

Another Earth (2011) (*Film*) (From Philip Cherian)

A cross between science fiction and fantasy, *Another Earth* tells the story of Rhoda Williams, a brilliant young girl whose life is turned around when she hears a story on the radio about a recently discovered Earth-like planet – a mirror Earth.

District 9 (2009) (*Film*) (From Philip Cherian)

A story about aliens who are forced to live in pathetic conditions on Earth, the film explores themes of humanity, xenophobia and social segregation.

The Man From Earth (2007) (*Film*) (From Philip Cherian)

John Oldman, a departing university professor, claims to be a Cro-Magnon (or Magdalenian caveman) who has secretly survived for more than 14,000 years. The film is centred around intellectual arguments between Oldman and his fellow faculty members.

All descriptions of the books, documentaries and movies have been taken and adapted from Wikipedia and Google Books.

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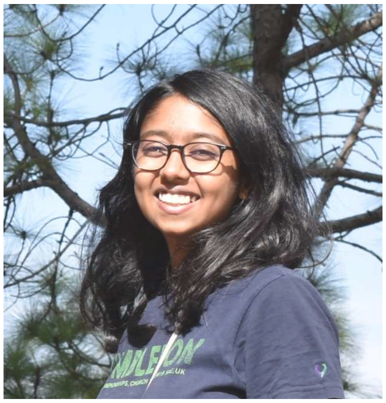

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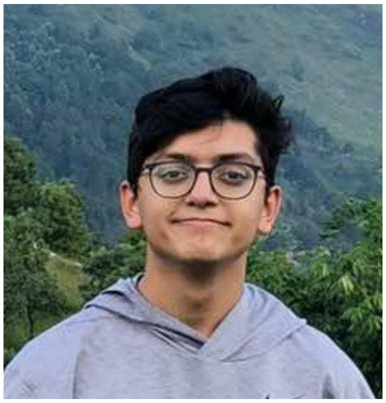

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"The highest forms of
understanding we can achieve are
laughter and human compassion."
~ Richard P. Feynman