PHYSICS NEWSLETTER

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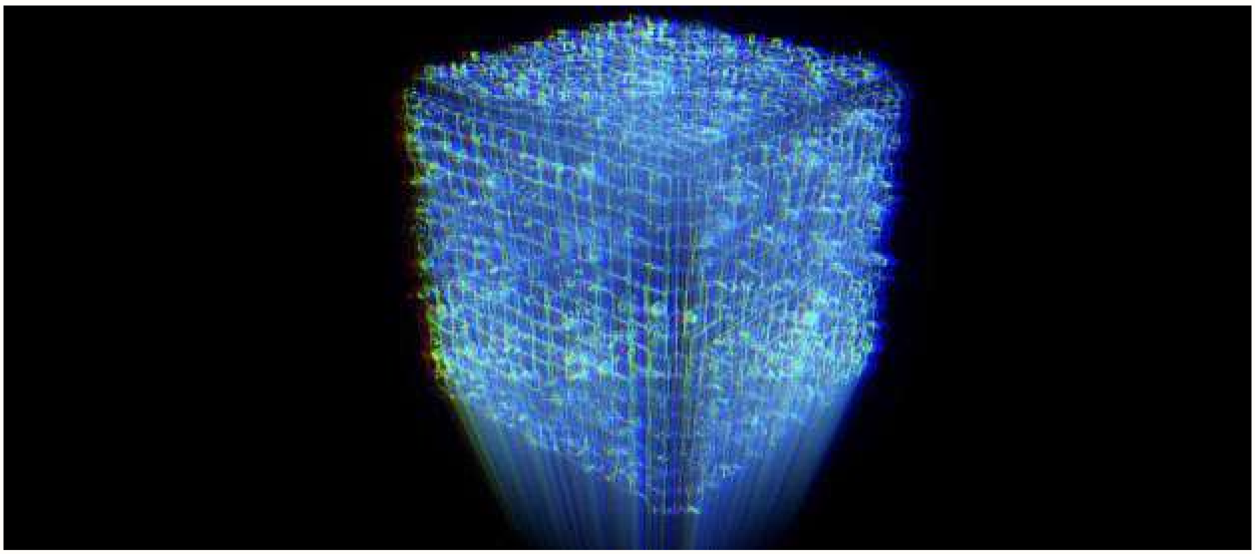
16th Edition - The Unknown



Welcome to the sixteenth edition of the Physics Newsletter! The theme of 'The Unknown' explores the mysterious aspects of physics which are difficult (and sometimes impossible) to understand. We hope you are surprised by something you learn!

Thank you to all the people who contributed to this edition of the newsletter: Ananya, Alice, Vanessa, Raga, Ruth and Aliza.

If you would like to be featured in any of our upcoming newsletters, just email Alice (17billwilks551@kechg.org.uk)!

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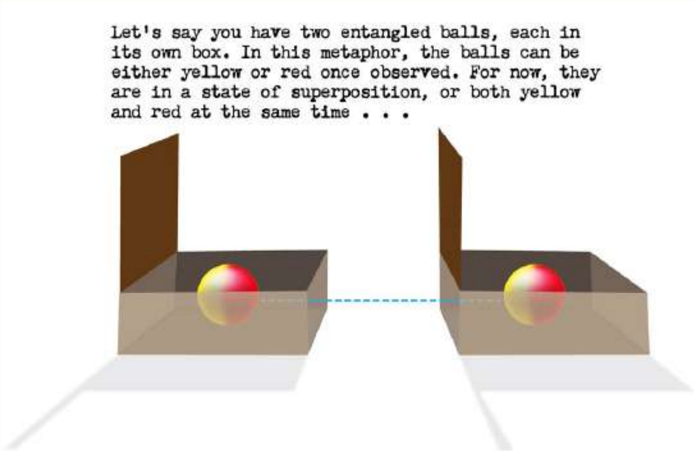
Keeping up to date…

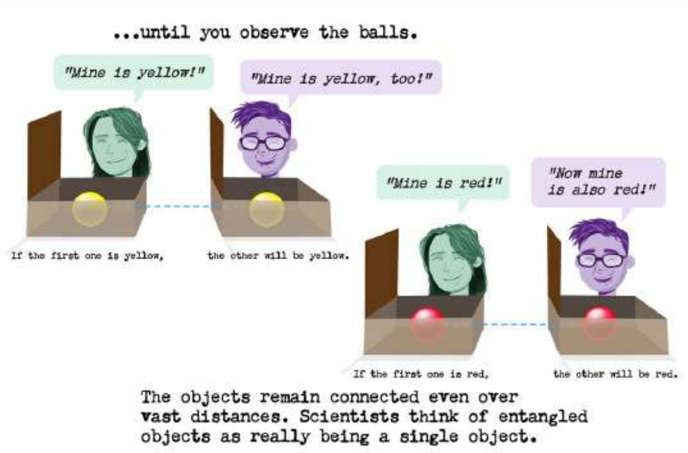
Physics in the News - Quantum entanglement and quantum computers

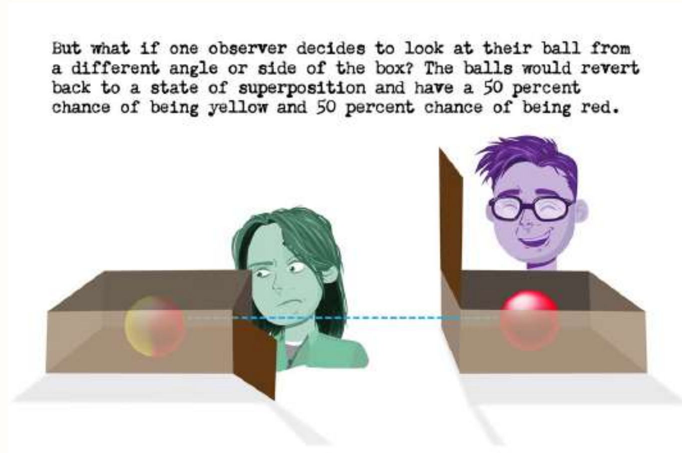
Einstein called quantum entanglement “spooky action at a distance”. Its spookiness has gradually faded away with the emergence of quantum computers. But what exactly is quantum entanglement? In simple terms, it means that an aspect of a particle (such as its spin) determines the aspect of its partner particle, no matter how many light years apart they are. This presents us with an astonishing conclusion: measuring an aspect of one particle in an entangled pair informs you what the aspect of the other particle is.

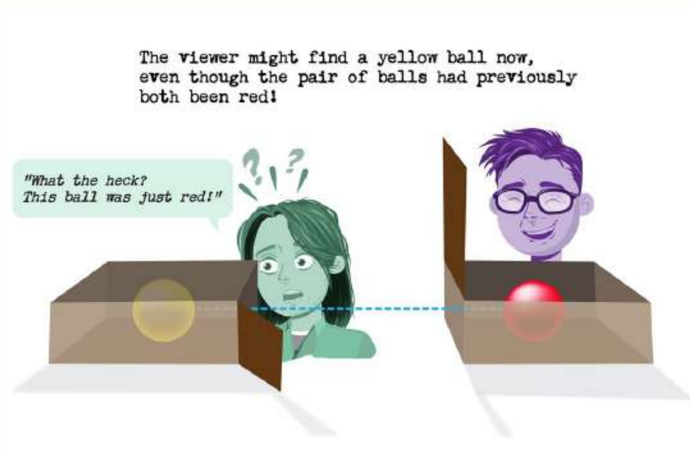
To understand this concept further, let us briefly touch upon quantum superposition. Quantum superposition is the idea that particles exist in multiple states at once until they are directly measured or observed. The presence of an observer in the system forces the particle to ‘choose’ a state. For example, spin can be measured as either up or down. Until the observer measures the spin of a particle it simultaneously exists as spin up *and* spin down. If a researcher measures the direction of the spin of the second particle after measuring the first particle they will find that they are always correlated. What can seem even more strange is that if the observer removes themselves from the system the particle will revert back to its state of superposition, despite having selected a state when previously measured. You may have heard of a famous thought experiment called Schrodinger’s cat, where a cat locked inside a box with a flask of poison remains simultaneously alive and dead—until the moment the box is opened. The cat is in a state of superposition until the observer opens the box, therefore entering the system. If we apply Schrodinger’s cat to quantum entanglement, imagine two cats in two boxes. You open one box and you sadly observe the cat as dead. In this case, the other cat is dead too, even if the second box is on the other side of the universe.

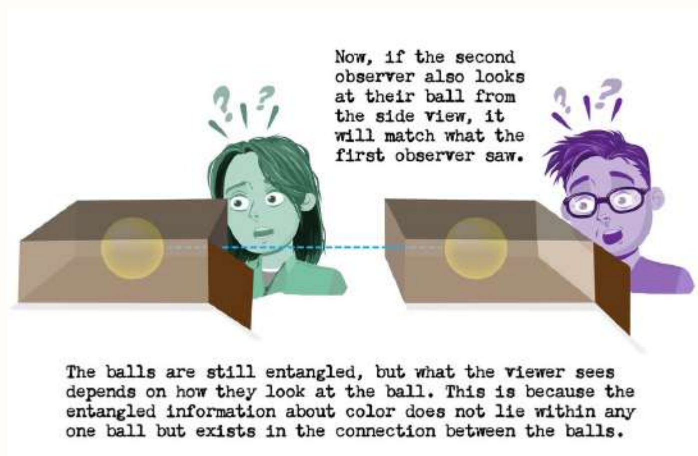
Here are some diagrams I found helpful to visualise these sorts of situations:











You might be wondering how this is possible. Are the particles communicating with each other? The short answer is no. The information transmitted between the particles would have to travel faster than the speed of light if this was the case. We know from Einstein's theory of special relativity that nothing is faster than the speed of light. This is why Einstein believed in 'hidden variables' - the entangled particles might have always been spin up or spin down but that information was hidden from us until we measured it. However, thanks to theoretical work by Bell and others since the 1970s, scientists have ruled out local hidden variable theories. Changing the angle the experiments were viewed from changed the outcome which means that aspects of the particle like its spin are not predetermined. This also explains why quantum entanglement cannot be used to send information faster than the speed of light - the state of the particle is completely random and information is not transmitted between the two entangled particles.

Now that we have a better understanding of quantum entanglement we can understand how it is used in quantum computers. In classical (traditional) computing a binary bit is the basic unit of information that can be transmitted. In quantum computing, a qubit is the basic unit of information. A binary bit can either be 0 or 1 but a qubit (thanks to quantum superposition) can be 0 and 1 at the same time. Therefore, two qubits can represent four states - 00, 01, 10, or 11. Along with the fact that changing the state of an entangled qubit changes the state of a paired qubit immediately, this improves the processing speed of quantum computers. The future of quantum computing is vast and it could even be used to speed up the search for dark matter due to its amazing processing ability. The ultimate machine of the future is likely to be the quantum computer. And it's all thanks to quantum entanglement.

References:
Quantum Entanglement Isn't All That Spooky After All - Scientific American.
What is quantum entanglement? A physicist explains Einstein's 'spooky action at a distance'
Quantum Entanglement: What is it & Why is it Important in 2023?
What Is Quantum Entanglement? - IEEE Spectrum
What Is Entanglement and Why Is It Important?
Entanglement Made Simple | Quanta Magazine
Quantum entanglement: the 'spooky' science behind physics Nobel
Physicists share 2022 Nobel Prize in Physics for insights into the spooky world of quantum mechanics
Quantum computing for the qubit curious).
Lecture 14, Thurs March 2: Nonlocal Games - this lecture goes into more detail about quantum information.
Bell State ZZ-Measurement | IBM Quantum Learning - learn to program quantum systems!
A book I would recommend if you want to read more about quantum physics in general is Helgoland by Carlo Rovelli.

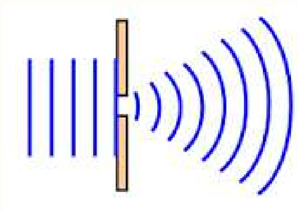
Ruth Rafeeq 13MP

Working with light…

The Physics behind Holograms

Holograms made from lasers have existed in sci-fi for almost half a century, but have now become a reality- all down to a little manipulation of light!

Light waves interfere with each other and diffract, projecting an image that exists in a different space- but what does that mean? Interference is the result of two waves colliding with each other and therefore interrupting their patterns, in a way combining the two. If both waves are at an amplitude of 2cm when they meet (which is way bigger than they'd actually be!) their interference would cause an amplitude of 4cm. When interference results in a larger amplitude, it's constructive; when the amplitude is smaller than before, it's destructive.
Diffraction is the way waves spread out when travelling around an obstacle. Instead of just going straight ahead, they bend around corners and spread out.

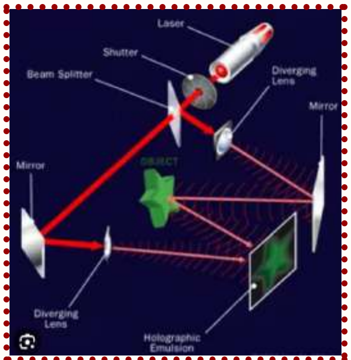


So, how is this used to create a hologram? Firstly a laser is used to produce a monochromatic beam of light (light with only one wavelength). This beam is then split into two using a beam splitter. One beam is called the reference beam and the other called the object beam. Both of the beams go through a lens which causes them to spread out.

Using mirrors, the object beam is directed towards the object the holograph will be created from and reflects off its 3D surface. This can change the phase difference of the object beam compared to the reference beam. Also, parts of the object that absorbed more light would create a less intense reflection, while parts of the object that absorbed less light would create a more intense reflection. All this means the object beam's amplitude, intensity and phase changes depending on the object it reflected off.

After this, more mirrors are used to direct the object beam and the original reference beam towards a plate that can capture light. As the light from the two lasers meet inside the plate, they interfere with each other. A pattern of light and dark spots is created, based on how the object beam had changed from the reference beam, and trapped in the holographic plate.

But how do we actually see the object? Well, a separate monochromatic light source, like another laser, is shone at the holographic plate, (the colour of the laser will be the colour of the hologram). This light can reflect off the spots in the interference pattern. More importantly, the space between the spots now act as small slits, causing the laser beam to undergo diffraction. The diffracted light spreads out as it travels towards the observer, projecting an image that looks just like the object.



The hologram appears to be 3D, meaning it will appear different as you walk around it. As the object beam could only reflect off the object's surface, if the hologram is split in half, it will project two smaller images of the object, instead of actually splitting the image. This is just one type of hologram - reflection holograms.

Unfortunately, many depictions of holograms in science fiction aren't completely replicable in real life, as it is very hard to create an actual 3D moving hologram. The 'holograms' that people may have seen at theme parks and haunted houses are usually created using Pepper's Ghost Effect. This uses a semi-transparent mirror to reflect an image or video. As our brain perceives reflections as existing inside the mirror, we think we see a '3D' video made out of light!

Don't lose hope though- a few decades ago the possibility of holograms even existing to this degree seemed impossible. Soon enough we'll be able to live out our totally spies fantasies- there's always more research to be done!

By Aliza Shams and Ananya Balaji

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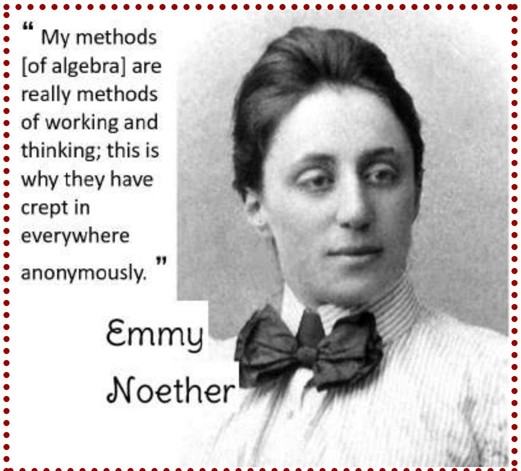
https://www.theguardian.com/technology/2018/may/22/star-wars-holograms-3d-images-future-holochess-princess-leia
https://youtu.be/oh4VtPBofAg?si=toIUTSAHwELY_xsr
https://phys.org/news/2020-08-true-holographic-movies-grasp.html#:~:text=But%20researchers%20at%20Tokyo%20University,projectors%20of%20the%2019th%20century (Idea of a hologram movie being developed in Tokyo University of Agriculture and Technology)

Where maths meets physics...

Women in Physics: Emmy Noether



Emmy Noether was a German mathematician who contributed greatly to ideas on symmetries in physics. However, as a woman in this field during the 1920s, she faced injustice and discrimination in the workplace. She started working at the University of Göttingen in 1915 but only received a salary in 1923. She was forced to leave ten years later by the Nazis because she was Jewish and had leftist political views.

Noether’s breakthrough was establishing a link between conservation laws and symmetries. A conservation law, such as the conservation of energy, states that a particular quantity must remain constant. Energy cannot be created or destroyed. Symmetries describe changes that can be made without altering how an object looks or acts. As for how this relates to physics - equations don’t change in different places in time or space. Noether’s theorem states that every conservation law has an associated symmetry and vice versa. This theorem was used to build the foundation of the standard model of particle physics and Noether’s work is still used today to formulate new theories. Noether’s theorem is relevant for continuous symmetries, which means that the symmetries hold no matter how far you move in space or time. An example is translation symmetry which means that the laws of physics remain the same as you move around the universe. Energy conservation comes from translation symmetry in time while conservation of momentum comes from translation symmetry in space.

But there was a problem. In Einstein’s theory of relativity, space and time are relative, not absolute, which made conservation laws harder to understand. Two German mathematicians, Hilbert and Klein had been trying to write equations for the conservation of energy within the framework of general relativity but ran into a ‘tautology’(the same thing said twice in different words) - the equation was like writing 0 = 0, but this had no physical significance. The duo asked Noether to help them and she showed them that this strange conservation law belonged to a group of theories known as ‘generally covariant’. In these theories, the equations hold whether you’re moving at constant speed or accelerating towards almost the speed of light. This is because both sides of the theory’s equations change in sync. This is the basis of Noether’s second theorem: generally covariant theories such as general relativity will have these non-traditional conservation laws. Noether's true genius was being able to fit specific concepts into a broader mathematical context.

If you're interested in learning more about symmetries, perhaps take a look into broken symmetries, which I find really interesting. For example, a broken symmetry in the very first second of the universe created a matter-dominated universe rather than there being equal amounts of matter and antimatter. Another broken symmetry caused the weak nuclear force and electromagnetic force to have very different strengths.

References:
In her short life, mathematician Emmy Noether changed the face of physics
Emmy Noether | Biography & Facts | Britannica
Emmy Noether | Mathematician who proved Noether's theorem | New Scientist

Ruth Rafeeq 13MP

Physics in the Real World: Unanswered Questions

Source: https://www.forbes.com/sites/duncanmadden/2023/04/12/what-causes-turbulence-on-flights--and-is-it-dangerous/

Of the remaining unanswered questions in physics, many are philosophical: What is dark matter? Is there a Theory of Everything? Why does time flow forwards? While these mysteries are deeply interesting, they are also very difficult to understand and can feel very separate from our lives. But tucked away at the bottom of one of these lists, you might just find turbulence: the everyday phenomenon that no one understands.

Turbulence occurs inside and around you: in blood flowing through arteries, smoke leaving a chimney and storm clouds in the air. If you travelled abroad this summer, you may have experienced turbulence on the plane. Modelling turbulence is an incredibly useful tool for engineers because it is such a common phenomenon. In fact, the behaviour of all fluids can be classified as either laminar or turbulent. Orderly laminar flow where water falls without disruption, such as water running from a tap, can be predicted precisely - no problems there. But turbulent flow is chaotic and there are no existing models that can perfectly predict turbulent behaviour.

Known to some as the last unsolved problem of classical mechanics, the Navier-Stokes equations describing turbulence are very poorly understood. To avoid the problem of describing the motion of liquids, gases, and plasmas, engineers must make ‘closure assumptions’, using average values and ignoring fluctuations to produce approximate solutions for practical applications. In microfluidics - the study of flow on very small scales - attempting to model with the equations becomes impractical. It is easier to use simplified forms of the Navier-Stokes equations, such as the Euler equation, which removes all the terms describing viscosity.

The problem with the Navier-Stokes equations is that they might actually be unsolvable. Because they have a non-linear structure, a closure problem arises - the equations require an infinite number of solutions, making them impossible to solve classically. Even if there are solutions to be found, there is no way of telling whether the solutions are unique, and whether they would be useful - for example, they may not fully describe fluids, instead containing indefinable points called singularities.

The Navier-Stokes equations are one of the seven Millennium Prize problems selected by the Clay Mathematics Institute in 2000. These are famously complex mathematical problems, so difficult to solve that a one million dollar prize is promised for the first correct solution to each. Solutions to these problems would substantially drive progress in mathematics and, in the case of the Navier-Stokes equations, solutions would also prove very important for modelling in many fields of physical sciences and engineering. Only one Millennium Problem has been solved so far, but the 19th century problem of modelling turbulence remains unsolved, as it has done for nearly 200 years.

So, next time the weather forecast is wrong, try to forgive the BBC - it might be that the weather is not only difficult to predict, but fundamentally impossible.

Alice Bill Wilks, 13CL

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https://glossary.ametsoc.org/wiki/Closure_problem
https://www.simscale.com/docs/simwiki/numerics-background/what-are-the-navier-stokes-equations/
https://www.mentalfloss.com/article/567856/common-things-science-hasnt-figured-out
https://www.claymath.org/millennium-problems/
https://www.diva-portal.org/smash/get/diva2:996740/FULLTEXT01.pdf

Experience: StemSMART Residential

https://www.undergraduate.study.cam.ac.uk/stem-smart

STEM SMART (Subject Mastery and Attainment Raising Tuition) is a widening participation initiative from the University of Cambridge. The programme is split into three phases, with Phase 1 lasting throughout Y12. Each week you are set an assignment of questions on Isaac physics for all of your STEM subjects. There are also weekly tutorials, where academic staff explain solutions to the questions. Attending these sessions and doing the questions all count as engagement, allowing you to progress to the next phase and the residential. STEM SMART has helped us consolidate our academic knowledge and presented challenging concepts, which made us learn to persevere.

Fortunately, we progressed to the next phase and we were invited to a residential at the University of Cambridge during the summer holidays. It was a week packed with lectures in maths, physics, chemistry and biology. We were separated into different Colleges based on our subjects, allowing us to meet the people that we had spent the weekly tutorials with as well as playing fun games and quizzes. Each college had different activities: Fitzwillam provided tours and icebreaker activities on the first day, while St Catherines set up an escape room (with STEM subjects involved, of course!).

All the colleges offered a formal dinner for all the students to participate in. This involved a three course meal with the fellows (senior members of faculty at Cambridge) who were dressed in very formal attire.

The actual sessions were very interesting with lots of content being taught, as well as preparation for entrance exams such as the ENGAA and NSAA. These sessions were extremely in depth, with some of them entering into university-level content. There were also some more humorous moments, such as questions asking us to give answers as a multiple of the volume of the Earth. It was a relaxed environment, where everyone felt able to ask questions and clear any doubts. The questions supplied to us really aided in our understanding, even if we were taught further maths content without our knowledge!

This year's deadline to apply for the programme is 31st October 2023 so make sure to sign up.

Vanessa George and Sai Raga Navili, 13P

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Dates to know:

1. **Beamline for Schools Competition (article in the next newsletter!): submissions from January to April 2024**

   An international competition for designing an experiment to be performed at a high energy particle accelerator. For Beamline for Schools 2024, the three winning teams will realise their experiments at CERN and DESY. All winners will be supported by a team of professional scientists.

   https://beamline-for-schools.web.cern.ch/sites/default/files/Invitation_BL4S_2024.pdf

2. **Isaac Physics Mentoring Scheme: any time from September**

   For Years 11 to 13, this is a super-curricular opportunity (great for your personal statement!) where you get set weekly problem solving activities. At the end of the school year you will receive a certificate with the number of questions completed.

   https://isaacphysics.org/pages/mentor_menu?stage=all

3. **University of Oxford Physics Department events**

   For Years 10 and 12 - have a look (for lots of taster days and programmes)!

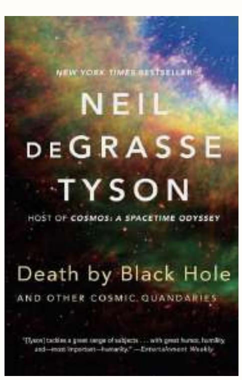
   https://www.physics.ox.ac.uk/engage/schools/secondary-schools

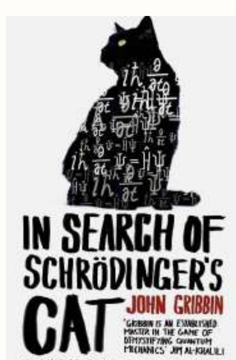
4. **Physics society is every Tuesday Week B in Lab 10, second half of lunch!**

5. **Engineering society is every Thursday in Room 27 at 1pm!**

Get involved!

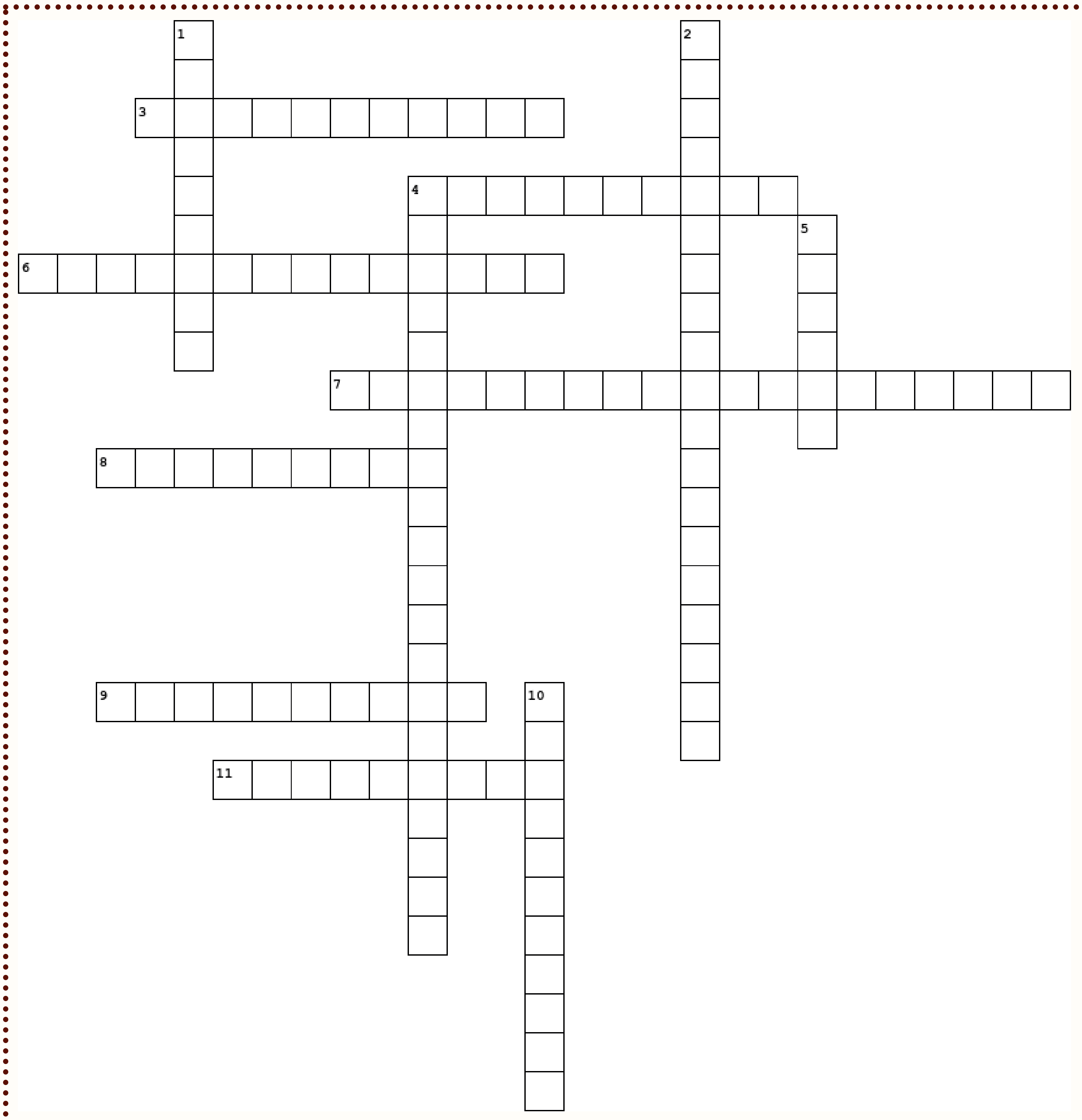
Here are some titles on theme with 'The Unknown' from the Physics lending library at the back of Lab 10. If you decide to borrow a book, send in your book reviews to feature in the next edition!





Crossword!

Spooky Physics



Submit your answers to 17billwilks551@kechg.org.uk for a mention in the next newsletter!

CLUES:

Across

3. our universe might not be as stable as we think and could decay into something new

4. matter that cannot be directly observed

6. the strongest and brightest explosion in the universe, generated through the formation of black holes

7. the science behind things that glow in the dark - Einstein won the Nobel Prize in 1921 for explaining this

8. a hypothetical region of spacetime that cannot be entered from the outside

9. an advanced civilisation with enough computer power could run this in such an elaborate fashion to create artificial minds

11. a region of spacetime where gravity is so strong that nothing, not even light, can escape

Down

1. a potential end for the universe due to infinite expansion

2. two particles billions of light years apart can be intimately linked

4. maybe many alien civilisations do exist but they are silent and hostile, protecting themselves from other potentially hostile civilisations

5. the solid form of CO_2 which can be used to create a spooky fog effect

10. a barrier to development that makes our chances of finding intelligent alien civilisations extremely rare (have we already encountered this...?)

blackhole • dark forest hypothesis • dark matter • dry ice • false vacuum • gamma ray bursts • great filter • heat death • photoelectric effect • quantum entanglement • simulation • white hole

Answers to the previous crossword: