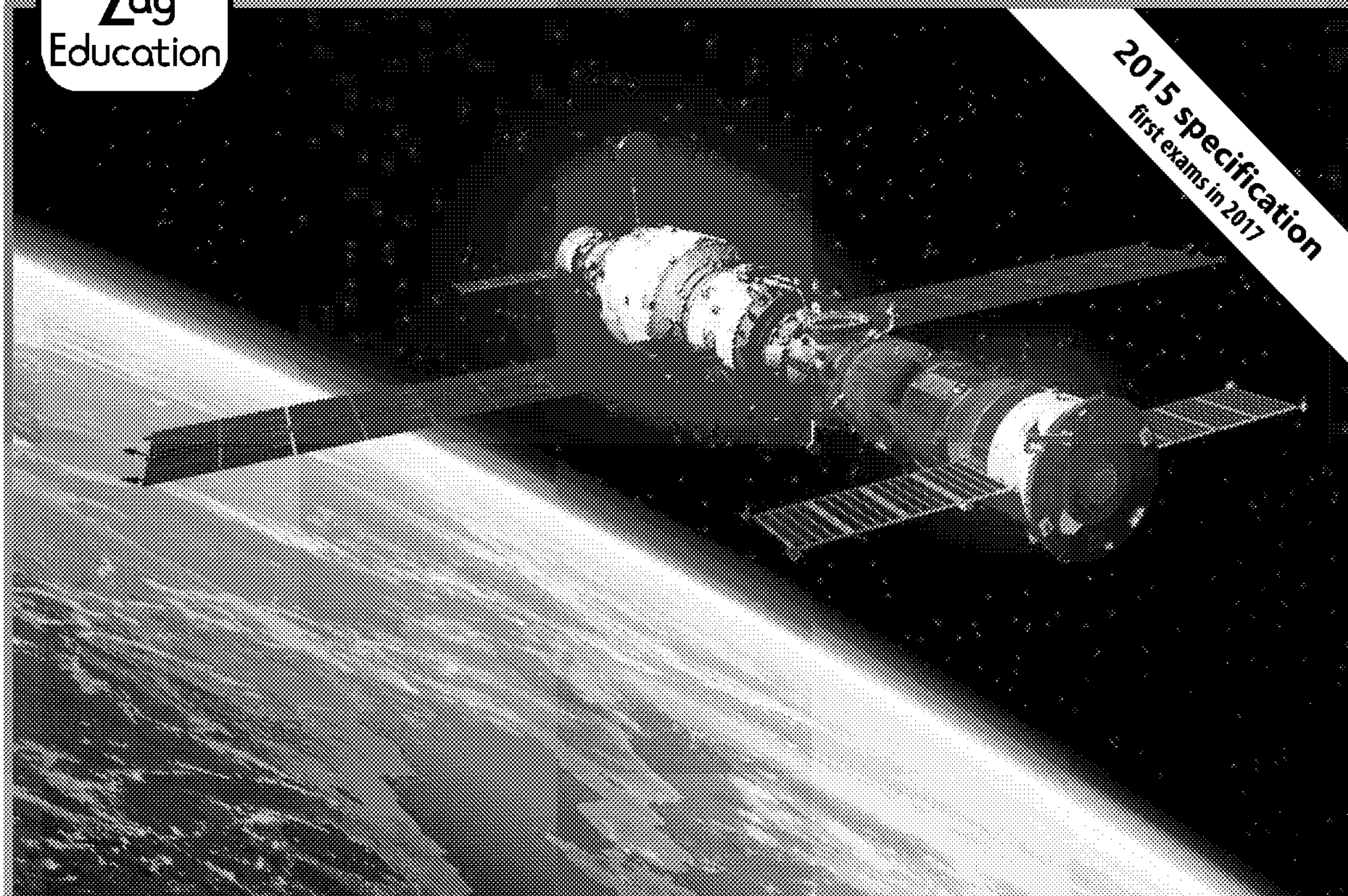
Physics

A Level | OCR A | H556



Stretch and Challenge Articles

for A Level OCR Physics A

Year 1 (Modules 1–4)

zigzageducation.co.uk

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Contents

Teacher's Introduction

These 'Stretch and Challenge' articles are designed to provide stimulation and new challenges for Physics OCR A Level students.

The pack contains 13 articles that cover areas of topical interest to physicists. The articles reach beyond the frontiers of the specification, although there are links to the OCR Physics A Level Year 1 content.

The aim of the resource is to challenge the most capable and engaged physics students. However, it should also be accessible to students of a range of ability levels as the articles add to the specification knowledge. However, the aim of the resource is to be challenging.

For each article, a mix of the following activities is included:

- comprehension questions to ensure understanding of the material and link ideas in the articles to core concepts in physics
- discussion questions to encourage debate on topical issues and wider scientific and ethical questions
- extension tasks that encourage students to conduct further research and support them to structure a written piece

Each article has a link to the specification, but also goes beyond the specification, including recent discoveries, case studies and applications of theories to the wider natural world.

Each article is between 1,000 and 2,000 words, and is expected to take a student approximately 30 minutes to read. The discussion questions can be whole-class activities, guided by the teacher, or small-group activities to encourage less-confident students to take part. The extension activities take a range of forms (individual and pair work), while the comprehension questions should be attempted individually.

All resources can be photocopied in black and white. We hope you enjoy reading and using these resources.

June 2019

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It's Not Exactly Rocket Sci

3.4.1 Force, energy and momentum

Keywords

Exhaust gases	The burnt propellant that exit th en ne or a rocket at high ve
Orbit	The path of an obje as is tionally bound to another ob
Eccentricity	The measure ellipse is stretched compared to a

Rockets have t u space, allowed us to build an array of satellites for comm ons, to send probes deep into the solar system and interstellar n. But realistically, how hard is the science behind them?

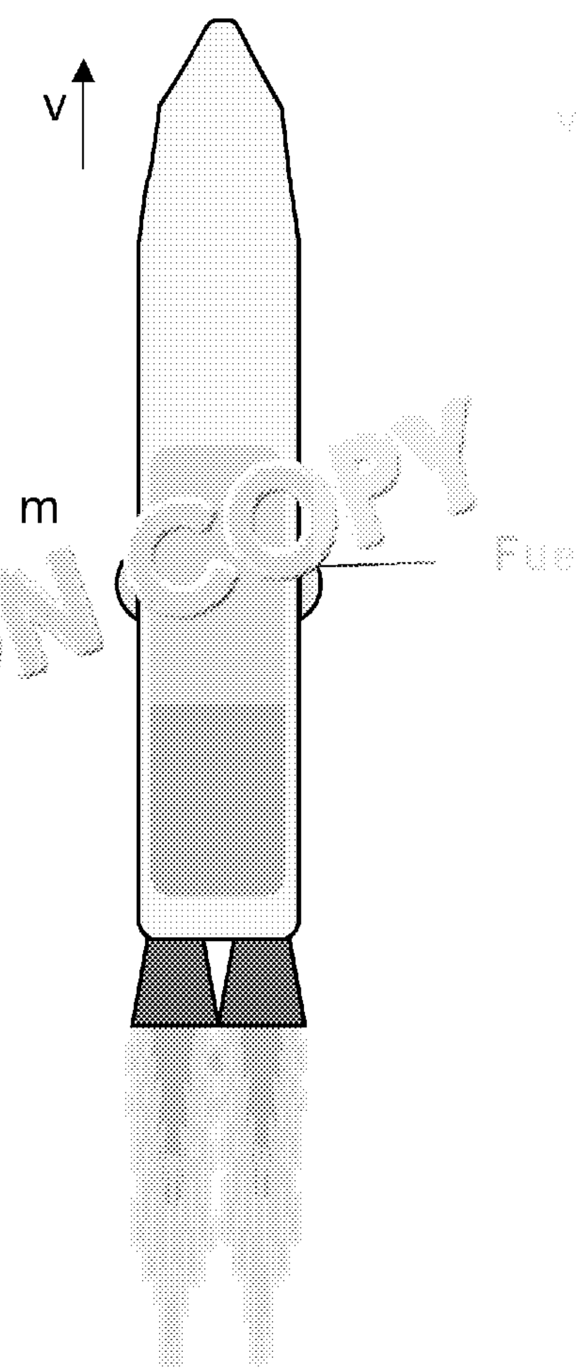
Rocket physics

Disclaimer: All of the following maths you will come across if you study A Level Maths.

You will be familiar with the motion of projectiles and how they behave in gravity. A rocket is a type of projectile, so the equations you have come across apply. The issue with rockets is the majority of their mass is their fuel. They use this fuel as they launch, meaning their mass changes throughout the flight.

To start let's consider a rocket at t t times during its launch, t a

To conserve he momentum due au released between t_1 and ual the change in momentum of t Let's build an equation that describes this in terms of the impulses experienced by the rocket and exhaust gases between t_1 and t_2 (ignoring gravity and air resistance):



t = t_1

Initial momentum of rocket and fuel.

$$mv = -\delta m v_e + (m - \delta m)(v + \delta v)$$

Final momentum of exhaust gases. It's negative becau do

Final momentum of rocket and un e

Key
m – Initial mass of rocke
δm – Change in mass o
v – Initial velocity of roc
δv – Change in velocity
δm_e – Change in mass o
v_e – Velocity of exhaust

Expanding this gives:

$$mv = -v_e\delta m + mv + m\delta v - v\delta m - \delta m\delta v$$

We can ignore the last term $\delta m\delta v$ because we assume the change in mass and velocity is small, making this term negligible. Cancelling other terms gives:

$$0 = -v_e\delta m - v\delta m + m\delta v$$

This equation describes the motion between t_1 and t_2, dividing by the change in time to get a more general equation with infinitesimal changes, i.e. a differential equation:

$$0 = m\frac{dv}{dt} - (v+v_e)\frac{dm}{dt}$$

$$m\frac{dv}{dt} = (v + v_e)\frac{dm}{dt}$$

You may recongise the left-hand side as Newton's second law, the right-hand side is a slight variation of

$$T = (v + v_e)\frac{dm}{dt}$$

Key
T – Thrust

this with a changing mass. So the force, also called the thrust, acting on the rocket is given by:

The term $v + v_e$ is the velocity of the exhaust gases relative to the rocket, i.e. the speed the exhaust gases leave the rocket. This is assumed to be a constant throughout the flight. Therefore, our equation says thrust is proportional to the change in mass, i.e. the more exhaust gas the rocket spits out the back, the larger the thrust on the rocket – makes sense.

δv is given by:

$$\delta v = \left(v + v_e\right)\frac{\delta m}{m}$$

Key
v_i – Initial velocity of rocket
v_f – Final velocity of rocket
m_i – Initial mass of rocket
m_f – Final mass of rocket

Integrating this gives:

$$v_f = \left(v + v_e\right)\ln\left(\frac{m_i}{m_f}\right) ...$$

$$\int_{v_i} \delta v = (v+v_e)\int_{m_f}^{m_i} \frac{1}{m}\delta m$$

$$v_f - v_i = \left(v + v_e\right)\ln\left(... \right)$$

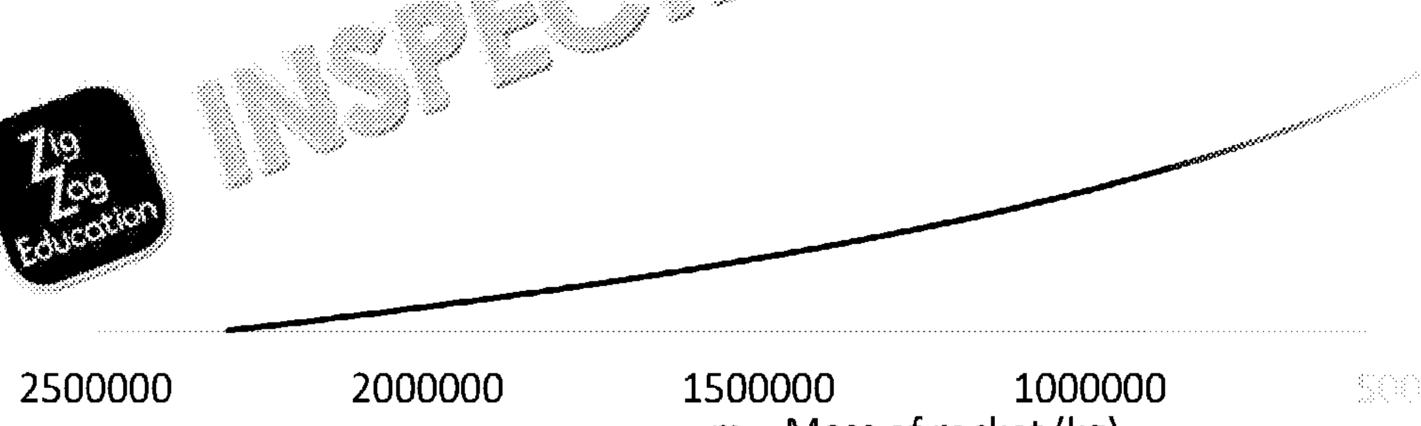
Which gives us the ve...
time after some initial...
that $v + v_e$ is a consta...

Below is a plot of this...
Notice how as the roc...
burning fuel, its accel...
without including air r...
altitude (less air at hig...
effects of air resistan...
resultant force acting...

... (v + v...

Key
F_r – Resultant force...
C – Drag coefficien...
ρ – Density of air
A – Cross-sectiona...
direction of motion...
g – Gravitational fi...

Note how the mass o...
the rocket, v ,the den...
field strength, g, and...
mass, $\frac{dm}{dt}$, are all variab...
on the rocket, and th...
vertically upwards th...
reality rockets will an...
the Earth. This is one...
science is so complic...



Orbital mechanics

Getting into space is the hard part. The vast majority of the mass of a rocket is the fuel for the launch stage.

During launch the rocket will angle itself so it ends up on a trajectory to its desired orbit, basically a projectile's trajectory with enough horizontal velocity that it constantly misses falling back down.

The rocket tends to have several stages (different engine designs work efficiently at different altitudes). Once the last stage has deployed the cargo into space, say a new space telescope, the stages drop out of orbit (although new commercial rockets land themselves, reducing costs). The telescope is now in free flight, only acted upon by the Earth's gravity.

An object can orbit the Earth (or any object with a gravitational pull) in four ways:

- circular
- elliptical
- parabolic
- hyperbolic

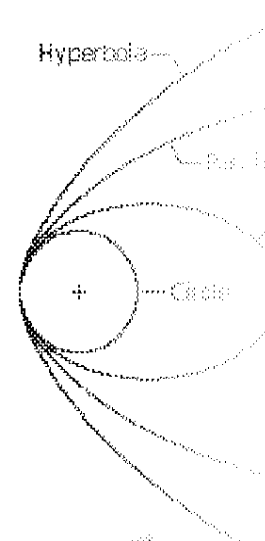
Circular orbits are realistically impossible and parabolic and hyperbolic orbits only describe fly-bys rather than a repetition of motion. Therefore, we will focus on elliptical orbits.

An ellipse is a stretched circle. Instead of one centre it has two, called focal points. The sum of the distance from one focal point, A, to a point on the ellipse, C, and the distance from the other focal point, B, to the point on the ellipse, C, is a constant.

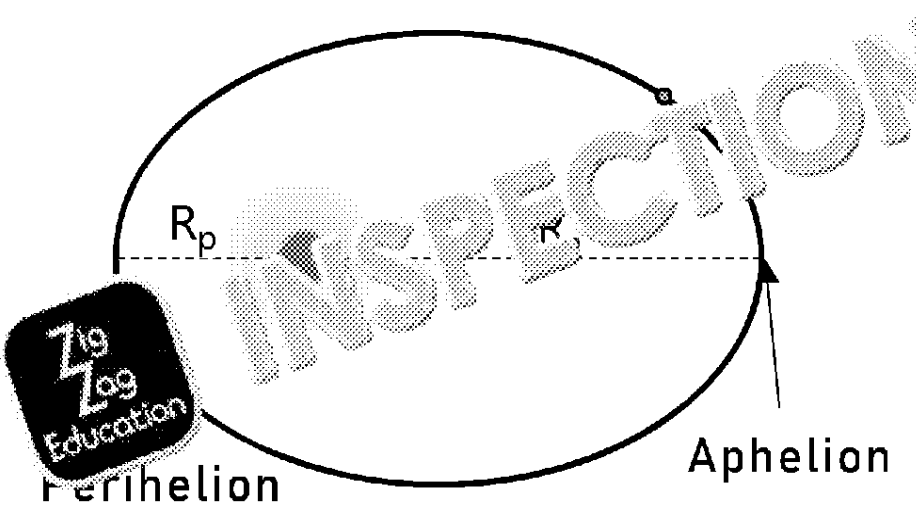
AC + BC = constant

The distance between a focal point and the centre of the ellipse is:

Where e is the eccentricity of the ellipse ($0 < e < 1$) and a is the semimajor axis (this distance is the same for both foci).



For the following explanation we will use the exmaple of a comet orbiting around the Sun. An elliptical orbit will arise when the comet enters the gravitational field of the Sun with a velocity not perpendicular to the gravitational force (all of the planets in our solar system have elliptical orbits around the Sun). The point in the orbit closest to the Sun is called the perihelion (periapsis for an object that isn't the Sun) and the point furthest from the Sun is called the aphelion (apoapsis for other objects).



... of Kepler's laws stat...

$R_a = a(1 + e)$

Combining these two gi...

Remember a = semimaj...

Orbital motion

Now we know the basics of ellipses, let's look at the motion of an object following an elliptical trajectory, i.e. an orbit. The potential energy of an object in a gravitational field is given by:

$$E_p = -\frac{GMm}{r}$$

And the kinetic energy of an object in motion is given by:

$$E_k = \frac{1}{2}mv^2$$

Energy is transferred between one and the other during an orbit, but the total energy is always constant. Therefore, picking two points in the orbit:

$$\frac{1}{2}mv_1^2 - \frac{GMm}{r_1} = \frac{1}{2}mv_2^2 - \frac{GMm}{r_2}$$

Rearranging gives:

$$v_1^2 - v_2^2 = 2GM\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

A useful feature of elliptical orbits is:

$$R_a v_a = R_p v_p$$

Rearranging and substituting this into our energy equation gives:

$$v_a = \sqrt{\frac{2GMR_p}{R_a(R_p + R_a)}} \quad \text{and} \quad v_p = \sqrt{\frac{2GMR_a}{R_p(R_p + R_a)}}$$

Rearranging these gives:

$$R_a = \frac{R_p}{\frac{2GM}{R_p v_p^2} - 1} \quad \text{and} \quad R_p = \frac{R_a}{\frac{2GM}{R_a v_a^2} - 1}$$

These are known as c
one dep… on the
ell… orbit is given

These equations desc
of an object can chan
rocket engines on. Th
axis and, therefore, th
orbiting object is give

Where r is the distan
ellipse and the orbitin
the velocity of an orbi
shape:

$v =$

… is the radius of the o
approaching the peri
This is why planets cl
those planets further

For a rocket that's p
the gravity of an obje
rocket will travel at its
perihelion. It is at thi
on will be most effect
potential is at its lowe
by the engine will not
gravitational potentia
transferred into kinet
Oberth effect.

Comprehension questions

1. At the beginning of its launch, a rocket turns its engines on to full power. The r of exhaust gases is 7500 kg s^{-1} and it leaves the rocket at 1200 m ... hat is t
2. State one mathematical property of ellipses.
3. What are the names given to the closest and furthest point ... orbit around
4. The orbit of Mars has an eccentricity of ... its semi-major axis is 2.28 × 10 when it travels through its perih... 06 ... m away from the Sun? The m

Discussion

...10 y... the aerospace industry have seen more private companies laun ... p new technologies, such as SpaceX and Blue Origin with their vertical-la ... mpanies leading the way in space exploration is a good or bad thing, and company were the first to send man to Mars.

Extension

The typical rocket is comprised of a main stage with either a second or a second an rocket launches with the main stage and drops it behind when it runs out of fuel. It and third stages at different points in the launch. This means unnecessary weight is but also allows engines attached to each stage to be specially designed to operate a (recall atmospheric pressure decreases with altitude). An alternative is to use an aer shape throughout the launch to adapt to the changing atmospheric pressure. Resea and write a report on your findings.

Special Effects

3.1 Motion

Keywords

Reference frame	A coordinate system specific to the reference in train which has its own reference frame compar
Electromagnetic radiation	Also known as light, this is an excitation in the el fundamental field in nature)
Paradox	A statement that, despite sounding true, leads to consequences

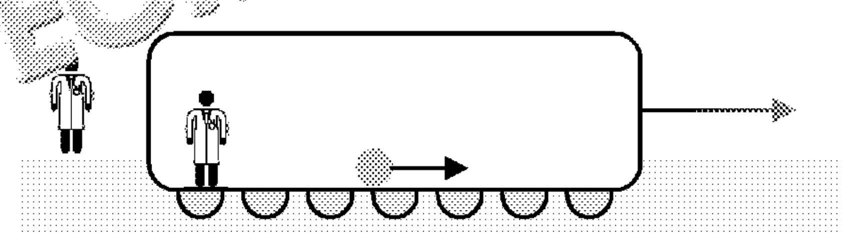
In 1905, Albert Einstein wrote and published one of the most influential scientific pa The paper brought together ideas about space, time, mass and energy, and solved widely discussed problems in physics at the time. This paper, *Zur Elektrodynamik bew Electrodynamics of Moving Bodies*, set out Einstein's theory of special relativity, whic the most important bases of modern physics.

It's all relative

One of the most important aspects of physics is the idea of **relativity**, the idea that equivalent. This is actually a quite simple idea:

Consider a passenger on a train with a ball. The train is entirely made of glass and can perfectly see everything happening inside. The train travels past the platform at

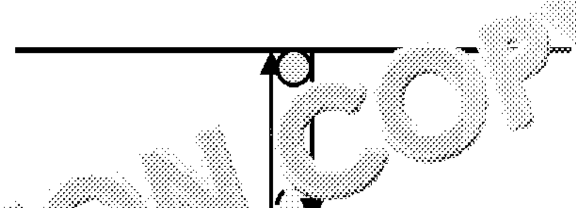
The passenger takes their ball and bowls it down the train aisle in the same directio scientist on the train kindly measures the ball's speed and confirms that it is travellin



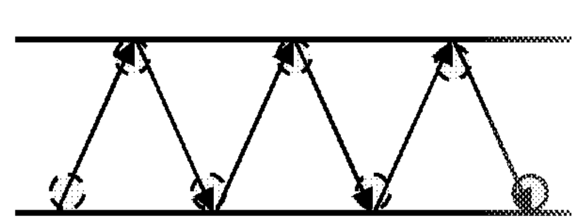
However, another scientist standing on the platform also measures the speed of the because they've measured the speed of the ball added to the speed of the train.

Neither scientist is wrong – the scientist on the train is correct in saying that the ball **reference frame of the train**, and the scientist on the platform is correct in saying 15 m s^{-1} in the **reference frame of the platform**.

Now instead of rolling the ball forwards, imagine the ball being rolled side to side, of the train. The scientist on the train sees the ball simply travelling back and forth



According to the scientist on the platform, however, the ball is travelling back and f the motion of the train



Again, both scientists are correct in their observations, but because of their different … different effects. Neither scientist is more right than the other, they're just measuring … different points.

In fact, all physics works exactly as you'd expect, no matter the reference frame, as long as it **isn't accelerating**. In any reference frame, momentum and energy are conserved, … fields act exactly the same. If the train were perfectly opaque with no windows, a passenger … know the train was moving at all, no matter which [illegible] experiments they perform … sped up, slowed down, or turned [illegible] though they might notice the engine …

This idea is known as **Galilean relativity**, and is a simple but crucial aspect of physics.

Travelling light

Between 1855 and 1873, a Scottish scientist called James Clark Maxwell published a … turned the idea of Galilean relativity on its head. In his papers, Maxwell set out the … describe how electromagnetic fields propagate. One crucial aspect of the Maxwell … electromagnetic waves travel at the speed of light, c, which is given by

$$c = \sqrt{\frac{1}{\mu_0 \varepsilon_0}}$$

where ε_0 is the permittivity of free space, and μ_0 is the permeability of free space. … electric and magnetic waves in a vacuum, and most importantly are constants. This … constant, with all light travelling at a fixed speed. This raised a … in which … travel at this fixed speed?

Think back to our train, but instead of [illegible] imagine the passenger is shining … According to Maxwell, the light should travel at c, but we have no indication which … light as travelling at c [illegible] measure c plus 10 m s^{-1}. Maxwell's equations … special reference frame in which light travelled at its 'correct' speed, in complete … frames equivalent in terms of physics.

… for this, the idea of an **aether** was put forwards. This aether was proposed … which light travelled at its true speed. Two scientists, Albert Michelson and Edward … experiments in an attempt to measure the effect of the aether. The experiments … light in different directions and at different times of the day – depending on the … of light should have varied slightly as the light travelled different paths through the …

Instead what was found was that the speed of light is constant, regardless of which … it from. The Michelson–Morley experiment would go on to be considered the most … time.

On the right track

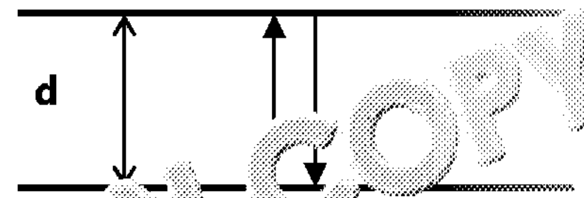
Einstein's solution to this problem couldn't have been simpler: he accepted … and …

Galilean relativity and the invariance of the speed of light form the two postulates of … relativity:

1. In an inertial (non-accelerating) reference frame, the laws of physics are invariant …
2. The speed of light in a vacuum is the same in all reference frames, independent of the motion …

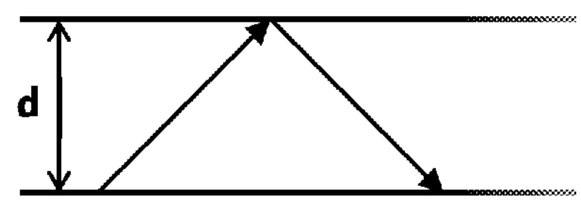
… as a starting point, Einstein made a startling claim: to account for these … would bend, stretch and squash to accommodate the measurements of different …

On our train, the passenger once again shines their laser; this time so that a single p
mirrors on either side of the aisle.



The time it takes for the photon to travel from one mirror to the other, and back to
$t = \frac{2d}{c}$.

The scientist on the platform sees something quite different, though. Instead of refl
also moving forward at the same speed as the train, much like the ball fr



This time the distance between the mirrors is d, but in the time taken for the photo
train and photon have moved forward by a distance vt.

This actually means that the photon has travelled further according to the scientist c
to the scientist on the train. If the speed of light is invariant, this can only mean one
longer to bounce from one mirror to the other and back according to the scientist c

We can even work out by how much the two scientists differ.

We first need to define the variables in the two reference frames.

On the train, the scientist measures a distance x and a time t for the photon's path.
measures a distance x' and time t'. Both scientists agree that the reference frames
each other.

For the scientist in the train:

x

and

$$t = \frac{2d}{c}$$

For the scientist on the platform:

$$x' = \sqrt{v^2t'^2 + 4d^2}$$

and

$$t' = \frac{\sqrt{v^2t'^2 + 4d^2}}{c}$$

The equation for x' just comes from Pythagoras' theorem – can you work it through yourself?

Now we can isolate t' in this equation:

$$t'^2(c^2 - v^2) = 4d^2$$

$$t'^2 = \frac{4d^2}{c^2 - v^2}$$

$$t'^2 = \frac{\frac{4d^2}{c^2}}{1 - \frac{v^2}{c^2}}$$

$$t' = \sqrt{\frac{\frac{4d^2}{c^2}}{1 - \frac{v^2}{c^2}}}$$

We know that $t = \frac{2d}{c}$, so

$$= \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}}$$

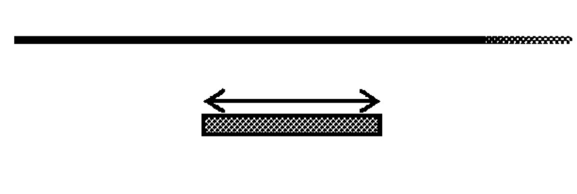
For a train travelling at 10 m s^{-1}, this distance is hardly not[illegible] 1 s measured [illegible] the platform would measure the time taken as 1.000 000 000[illegible] s (that's 15 zer[illegible]

If the train were to speed up though [illegible] becomes a lot more noticeable. 1 s on the train is measured [illegible] 05 s [illegible] at 87 % of the speed of light, the time [illegible] on the train becomes [illegible] from the platform. For this reason, speeds faste[illegible] be **[illegible]vist[illegible]**.

[illegible] the distance

The above proof shows how time can distort to maintain the speed of light, but spa[illegible]

Consider a rod lying along the aisle in the train.



The two scientists decide to measure the length of the rod by timing [illegible] it ta[illegible] one end to the other. The scientist on the train measures th[illegible] the [illegible] to b[illegible]

We know already that the two scientists mea[illegible]s, so they must also [illegible] scientist on the platform would meas[illegible] rod [illegible] of length L':

$$L' = L\sqrt{1 - \frac{v^2}{c^2}}$$

[illegible]d travelling at 95 % of the speed of light would be measured by a statio[illegible]

As a matter of fact

Time dilation and length contraction aren't just matters of theory, they're real exper don't see these effects in everyday life because they only become appr... it spee has ever travelled, but in the world of particle physics, travelling ... fractions of day occurrence.

When cosmic rays hit the upper atmosph... produced. Muons decay muon neutrino, and an electron ...

$\mu^- \rightarrow e^- + \nu_\mu + \overline{\nu_e}$

...cay ... average lifetime of 2.2 μs. This means that every single muon ...ng the ground, even if it was travelling at the speed of light. What is ins ... muons make it to the surface.

While this doesn't make sense for classical physics, special relativity makes it simple decay in the reference frame of someone standing on the Earth because they're tra lifetime increases.

Travelling at 0.996 *c*, the average lifetime extends from 2.2 μs to 25 μs – over ten ti

But what about the muons' reference frame? There still shouldn't be enough time before decaying! This can be explained by special relativity as well – the muons are distance from the upper atmosphere to the ground contracts, reducing the distance that the muons can cover a greater distance in the same amount of ... travelling

Twin peaks

There's a famous paradox in spe... people try to use to poke holes in

Imagine two twin... way, with only a few minutes difference in thei ... at speeds approaching the speed of light. After a short ... astronaut twin inside. Due to time dilation, what was only a short ti ...onger for Earth, just like the photon on the train. The astronaut twin re ...der than herself.

But wait! Since all reference frames are equivalent, this can be thought of from the the spaceship. In this point of view, it's the Earth that is speeding away at close to earthbound twin that stays young.

Which one is it? Does the effect not happen at all? Or is one of the reference fram why?

The answer is that reference frames are only equivalent when they're **not acceler** spaceship has to accelerate up to a fraction of the speed of light away fr... Earth an returning. This accelerating reference frame takes the problem ... realm of realm of **general relativity**. When making this correctio... that it is the much younger.

General relativity is another of Ei... As its name implies, it is a genera allowing similar ideas to ... accelerating reference frames. General relati important and ... of physics, and governs all gravitational interactions ...s a ... way to integrate general relativity and quantum mechanics, ...ay ... a theory which describes all of physics.

Comprehension questions

1. What are the two scientific principles that were at odds with each other in clas how did they lead to special relativity?
2. An electron travels through a particle accelerator at 2.38 × [illegible]. A scientist travelling around the particle accelerator in 880 ns. How long does this take fro electron?
3. How can the extended lifetime of a muon in a cosmic ray be explained from th observer on Earth and the reference frame of the muon?

Discussion

[illegible]tivity only applies to very high speeds, but that doesn't mean it can't hav t[illegible]. Try and come up with as many possible applications and technologies th relativity.

Extension

The ladder paradox is a special relativity paradox like the twin paradox discussed ab

In it, someone runs near the speed of light holding a ladder in the direction of their the ladder decreases. The person runs through a barn in which the ladder usually c the length contraction, the ladder should suddenly fit according to an observer at r closed. However, according to the runner, it is the barn that appears shorter so the greater extent.

Do some research and think about the problem yourself, and try and come up with

3.2 Forces in action

Keywords	
Monolithic	An object built with one piece
Orbit	The curved trajectory of ... caused by the gravitational att... orbits
Module	A self-contained unit that combines with other modules to mak...

The International Space Station (ISS) is the largest structure ever built by humans in... the necessary materials into space and constructing the structure in a mic... undertaking, but is worth the data and experience we gain about living and...

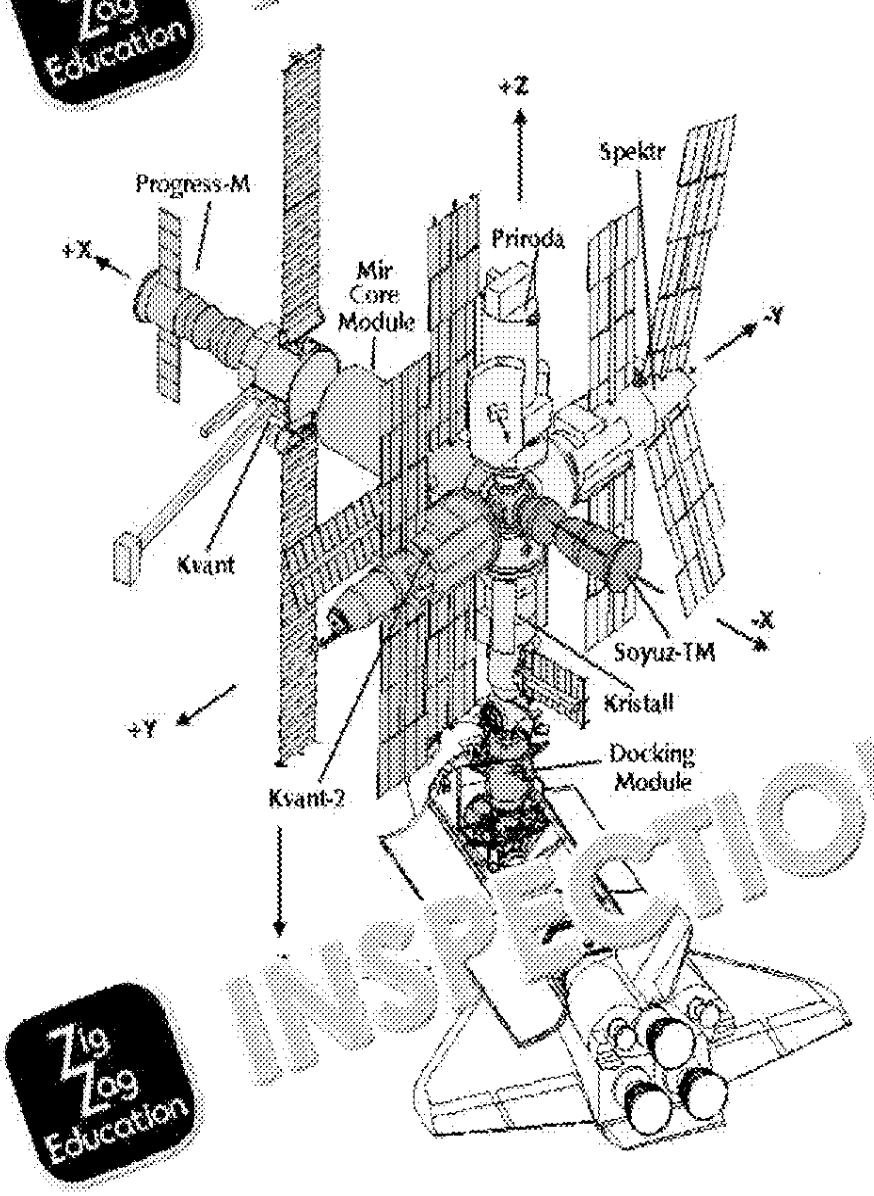
Before the ISS

The first ever space station was the Salyut 1; a monolithic (launched in one piece) space station launched on 19th April 1971 by the Soviet Union. It stayed in orbit for 175 days before re-entering on 11th October.

The following six Salyut missions throughout the seventies were all successful, apart from one which failed during its launch. All monolithic space stations were sent into space unmanned, so th... failed missions only resulted in financial loss.

A Soyuz ... Salyut 1

The last Salyut mission, Salyut 7, stayed in orbit ... longer than its predecessors, a total of 3216 days ... 1982 and 1991. However, it was only occupied by ... 816 days, up until June 1986. Salyut 7 provided the le... the transition between monolithic space stations and ... space stations, the type used today.



The space shuttle Atlantis docking with Mir

Using everything they had learn... Soviets launched their first mod... low Earth orbit in 1986. Mir was... modules and several other mod... These modules were built on Ea... using six launches of the Soviet ... the American space shuttle, insta... 1995.

This was the first long-term spac... human presence – the space sta... years, twelve and ... of which... had a continuous ... orbit ... longest such ... until it was s...

Mir was a centre for groundbreak... between scientists from seven co... Germany, Hungary, Japan and C... advantage of microgravity and ... including experiments into the e... humans, plants and animals; dev... which were previously impossibl... gravity; testing of space technolo... astrophysics experiments, includi... from space; and observations of...

of climate change, changing land use, weather systems and natural disasters. But M scientific laboratory – with tensions high surrounding the Soviet Union and its collap collaboration which broke language and cultural barriers was an important symbol

After the Soviet Union (USSR) collapsed in 1991, the operation of the space stat Russian Federal Space agency (now known as Roscosmos) who decided to deorbit 1999 due to a lack of funding. Mir broke up in the Earth's atmosphere in the early 21st March 2001. How a satellite behaves during its orbit is very unpredictable be speed trajectory through the increasing density of Earth's atmosphere introduces making any prediction of where the various fragments may end up difficult.

NASA also had space stations in orbit before the ISS was built. The first was Sky launched on the Saturn V rocket (the rocket that took man to the moon). Thre 1973 and 1979 before its re-entry above Perth, Australia on 11th July 1979. international media event creating excitement and panic, so much so the president on national television to calm the nation. NASA said the chance of debris hitting a

Building the ISS

The first module of the ISS was the Russian Zarya module, launched on 20th November 1998. Two weeks later, space shuttle Endeavour brought the Unity module to be connected to Zarya, laying the foundations of the American and Russian partnership to build the ISS that would later follow. The ISS wasn't manned until after 26th July 2000, when the third module, the Russian Zvezda was added. Since then, another 29 launches have taken up modules and sections built by NASA, Roscosmos, the Japanese Aerospace Exploration Agency (JAXA), the Canadian Space Agency (CSA) and the European Space Agency (ESA) to the space station to be fitted, making the ISS an international collaboration.

On 14th April 2001, space shuttle Endeavour took the Canadarm2 to the ISS, a robotic arm built by the CSA that helps with docking and maintenance of the ISS. On 8th April 2016, A Falcon 9 rocket launched by SpaceX took the Bigelow Expandable activity module to the space station. This module is flat-packed until it reaches its destination, then is inflated up to its operational size. The hope is for future space infrastructure to use a similar principl in launch vehicles. The launch by the Falcon 9 was the first time a private company to be fitted, and was the first module to be fitted in nearly five years.

The ISS is split into two parts, The US orbital section (USOS) and the Russian orbital section (ROS). Astronauts and cosmonauts can easily travel between the two, but generally stick to their own sections.

The ISS provides a microgravity and space environment for many experiments to be carried out in. Since January 2018, 230 people from 18 countries have visited the ISS. It only has a capacity of six people at one time, so astronauts and cosmonauts tend to stay at the space station for six months at a time. There have been exceptions, as in 2015/2016 when astronaut Scott Kelly and cosmonaut Mikhail Kornienko stayed on the ISS for a year. Scott Kelly has a twin, Mark, who stayed on Earth during this time. When Scott came back, the two were medically examined to determine the differences and changes the space environment causes to the human body.

A picture taken of the I board the space shuttl

The results provided more evidence the human body does indeed change in space:

- Our bones become less dense and muscles waste away – because of this, it's in astronauts to keep up a strict exercise regime, to remain healthy on their return
- Humans grow a few inches taller – without the constant pressure of gravity, ac fact, in January 2018, the three inches Japanese astronaut Norishige Kanai had over the 6 foot height limit for astronauts, and he feared he might be too tall t (Thankfully, this height limit has a little wiggle room and he made it home safe
- Although the space station has shielding, cosmic radiation is still much higher stint in space can raise an astronaut's risk of cancer. Astronauts can even see report seeing in flashes of light in their vision while in space, which passing through the eyes and producing reactions.
- There are also some unexpected effects; red blood cell production decreases, deform and produce eyesight problems, and changes to DNA have even

However, when an astronaut returns to Earth, most of these changes revert back to interesting change is the lengthening of telomeres, the end parts of chromosomes this mean that living in space makes you younger?

Another interesting finding from studying astronauts is the difference between men more research needs to be done, but preliminary findings suggest that women's eye impairment than men, whereas men are less likely to faint when standing after return lose less blood in space.

Breaking the ISS

All good things must come to an end and the ISS is no exception. NASA have com 2025, whereas Roscosmos have endorsed the ROS until 2024. Currently, the Soyuz supplies and astronauts to the ISS; however, this will change in 2019 and 2020 when and CTS-100 (Boeing) will come into operation. Talks are also underway to extend as well as a new joint partnership between NASA and Roscosmos to develop the re

Comprehension questions

1. In total, how may Salyut missions were successful?
2. What was significant about the re-entry of Skylab?
3. What are the names of the two sections of the ISS?
4. Name two changes to the human body when in space for extended periods of

Discussion

The research from the ISS helps us understand how humans can travel and live in sp is important to carry out this research.

Extension

The replacement for the ISS will likely be designed over the next 10 years to be ope In 20 years' time there will likely be an occupied base on the Moon and possibly more th Come up with properties the replacement for the ISS in a similar orbit around Earth space exploration in 20 years' time.

Fluid Dynamics: Going with t

3.2 Forces in action

Keywords

Fluid	A substance that easily flows ... to external force
Viscosity	The measure of resi... al forces by a fluid due to int
Fluid packet	A piece of a f... nt mass but changing volume and s

A fluid is a s... has no fixed shape but instead can flow and take the shap ... pl... all fluids. Fluid dynamics is the study of fluids as they chang ... variables involved in such a system makes it a very complex branch of ph ... of applications; from aerospace and marine engineering to rocket scien dynamics found in fusion reactors or stars.

A three-dimensional viscous fluid can be described with just five equations:

1. **A continuity equation**. This ensures that for a given volume in the fluid, the

   total mass in the volume + any new mass that enters the volume – any mas

   is continuous with time, i.e. we don't randomly gain/lose mass in our fluid.

2. **Three Navier–Stokes equations**. These equations describe how fl... packets fluids) interact with each other. There are three equations, ... spatial
3. **An energy equation**. Called the Bernoulli equ...ion, this e... that energy i

The Navier-Stoke...

These equations a... ...l of fluid dynamics. They are derived from sim Ne... th... still has not been proven if solutions for the equations ex ... or ... the big problems in mathematics, with a $1,000,000 prize for who

...utions from this equation, researchers instead use computers to basically they find the ones that work. This brute force approach will only give an approxima depends on the computing time and power. The longer the program runs the calcu computing power, the more precise the calculated solution is.

The Navier–Stokes equation describes fluids with Newtonian viscosity; any force wi the rate of change of velocity at the point, i.e. Newton's 2nd law. Most fluids have N of a non-Newtonian fluid is custard. It's possible to move a spoon through custard change in velocity will result in the custard in being very viscous and rigid.

The model used to describe fluids is similar to the particle model used to describe gases, but instead particles are replaced with fluid p... (also called fluid parcels). These are very small 'pieces' of ... constant mass but which can have a changing vo... an... sh... The Navier–Stokes equation describes how ... these ... packets interact with one another.

Based ... custard m/wat...

For simplicity we ... the Navier–Stokes equation in one dimension. E ... in ...

$$\frac{\partial v}{\partial t} + v\frac{\partial v}{dx} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \frac{4}{3}\frac{\eta}{\rho}\frac{\partial^2 v}{\partial x^2}$$

Note: The x direction is chosen to be in the horizontal plane, so gravity does not p... Navier–Stokes equation will have an extra gravitational term on the right-hand side

$\frac{\partial v}{\partial t}$	Partial derivative of the velocity with respect to time. This is called the **temporal derivative term** and makes the equation dynamic (changing with time).
$\frac{\partial v}{dx}$	Partial derivative of the velocity with respect to position, x.
$\frac{\partial p}{\partial x}$	Partial derivative of the pressure with respect to position, x.
$\frac{\partial^2 v}{\partial x^2}$	The second partial derivative of the velocity with respect to position, x.
ρ	Density of fluid
p	Pressure of fluid
η	Viscosity of fluid

The three-dimensional Navier–Stokes equation is a lot more complicated, because ... dimension are all dependent on each other.

The nondimensionalised Navier-Stokes equation

Computers can't understand equations of physics, they can only calculate solutions ... the computational physicists to understand the results. The ... equation of ph... first be nondimensionalised. This process basically removes all the units from each ... nondimensionalised 1D Navier–Stokes equation is:

$$\left(\frac{l_0}{t_0 v_0}\right)\frac{\partial v}{\partial t} + v\frac{\partial v}{dx} = -\left(\frac{p_0}{\rho v_0^2}\right)\frac{\partial p}{\partial x} + \left(\frac{\eta}{\rho v_0 l_0}\right)\frac{\partial^2 v}{\partial x^2}$$

...sionless Navier–Stokes equation has three constants that determine how ... la... the constant, the more effect that term has). If a constant is really small, we c...

$\frac{l_0}{t_0 v_0}$	This term determines the acceleration of fluid packets in a fluid ... fast (small t_0) compared to the size parameter of the system, l_0 ... be large.
$\frac{p_0}{\rho v_0^2}$	This term is the ratio of the pressure and kinetic energy of the s... kinetic energy, there is no dynamic system to describe and so ...
$\frac{\eta}{\rho v_0 l_0}$	This term is equal to the inverse of the **Reynolds number**, $\frac{1}{Re}$ ... inertial force ($\rho v_0 \propto$ momentum) and the viscous force (η is the ...

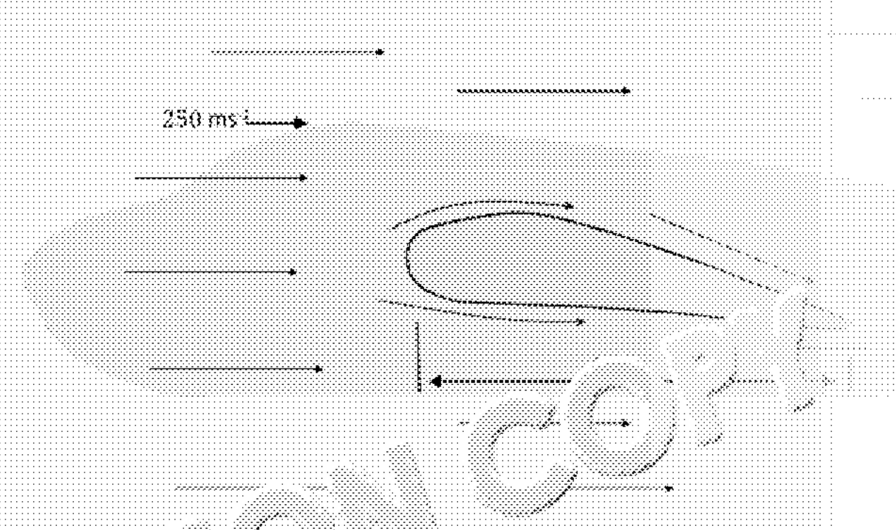
> Inertia is the property of an object to keep moving if it has velocity. ... force is, therefore ... an object exerts on other ... due to its motion (think of a ... plough pushing through snow).

The Reynolds number

This number is an important quantity in fluid dynamics. For low Reynolds numbers [illegible] dominated by laminar flow (comparable to sheets of paper sliding past [illegible] other), [illegible] numbers the flow of the fluid becomes more turbulent (compar[illegible] in a [illegible] useful because it doesn't matter what the exact values of [illegible] just what the [illegible] based on this principle that engineers will sca[illegible] object, say an aircraft, [illegible] keeping the Reynolds number const[illegible] engineers can test the aerodyn[illegible] tunnel using a much smaller [illegible]. As [illegible] the shape is the same, the Reynolds [illegible] model in the wind tu[illegible] aircraft during flight and the fluid dynamic[illegible]

Example

A plane flies at 250 m s^{-1} at an altitude of 15 km. The density and viscosity of air [illegible] $\rho = 0.20$ kg m^{-3} and $\eta = 1.4 \times 10^{-5}$ N s m^{-2}. The width of the cross section of the [illegible] $l_0 = 4.7$ m.



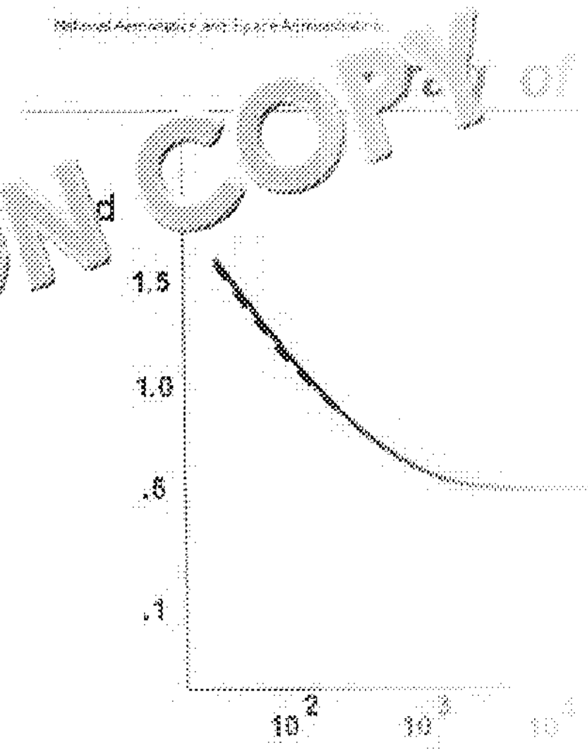
The Reynolds number in th[illegible] case [illegible]:

$$Re = \frac{\rho v_0 l_0}{\eta} = \frac{0.2 \times 250 \times 4.7}{1.4 \times 10^{-5}} = 1.7 \times 10^{7}$$

[illegible]mber is really large, meaning the fluid flow will be turbulent around the [illegible] [illegible]rse of the Reynolds number, $\frac{1}{Re}$, determines how much the inertial term co[illegible] equation. For this plane wing the term is negligible (viscosity forces dominate [illegible]

Dragging on

Any object that moves through a fluid will experience a drag force caused by the friction between the fluid packets and the object. The magnitude of the force can be calculated using the drag equation:



$$F_D = \frac{1}{2}\rho v^2 A C_D$$

The drag coefficient, C_D, depends on the shape of the object and the Reynolds number.

For low Reynolds numbers (high viscosity, low speed), the drag coefficient, C_D, is inversely proportional to the Reynolds number, Re. The result is that the drag force is proportional to the velocity of the object, $F_D \propto v$.

For high Reynolds numbers, the drag coefficient tends to stay constant, resulting in proportional to the square of the speed, $F_D \propto v^2$. Above is a graph showing the dra Reynolds number for a sphere.

F_D – Force exerted by fluid on object (N)
ρ – Density of fluid (kg m^{-3})
v – Velocity of fluid relative to object (m s^{-1})
A – Cross-sectional area of object (m^2)
C_D – Drag coefficient (dimensionless)

But what's the point?

The mentioned theory has a strong basis in many fields of research and develo ry are described below.

Weather prediction

Weather is the state of the atmosphere in a certain place at a certain time. The atm changes and interacts with itself in a highly complex manner. The sheer size of the the weather at a certain place very difficult. The weather also depends on the dyna from the Sun during the day, the rotation of the Earth, etc., which all further compl

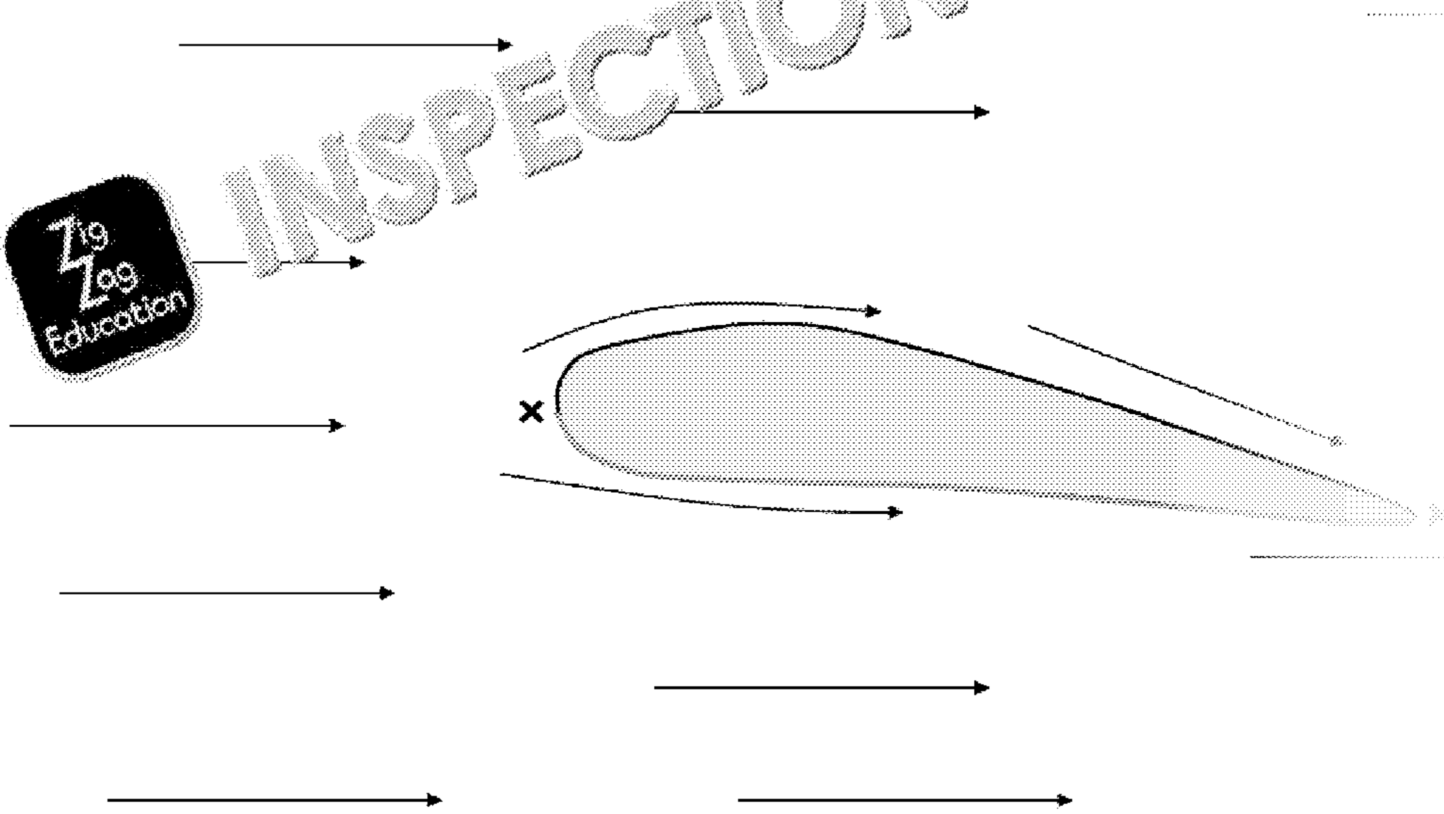
Fluid dynamics, mainly the Navier–Stokes equation, can be used in conjunction wit the possible future states of the weather for a certain place. The most likely outco people in that place.

The primary goal of predicting the weather isn't just so we can decide what clothes any changes that could lead to natural disasters such as storms, tornados, typhoons to increased risk of forest fires). ... Getting a warning out to the right pe correct precautions being taken, ultimately saving lives. Weather prediction also al precautions before the weather changes, increasing their yield and improving the fa ... weather ... to plan their route so as not to be caught in storms, reduc ...s.

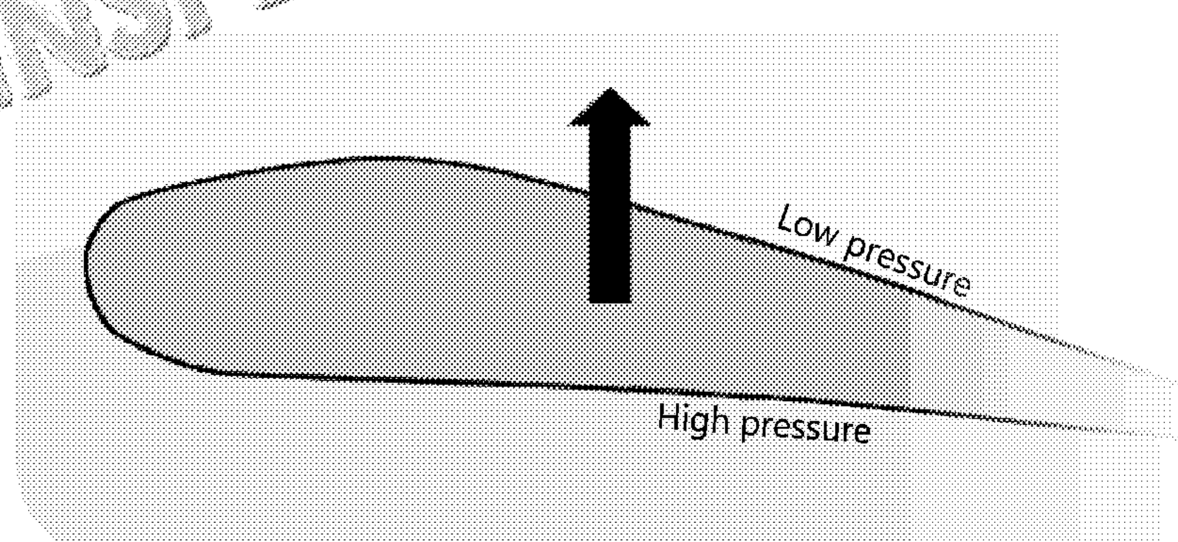
Aerofoils and hydrofoils

Anyone that has lived on Earth knows that air and water are in great abundance. Bo
behave in accordance with the theory of fluid dynamics. As humans have advanced
of fluids has been exploited to provide us with quicker means of transport, including

Fluids can be manipulated with an object called a foil. A diagram of a foil is shown



The foil splits the fluid into two parts at the first point marked with a ✗. The path
bottom of the foil (in grey) is shorter than the path along the top of the foil (in
both parts of the fluid to meet at the second ✗ at the same time. Therefore, the flui
flow faster. Bernoulli's principle states that an increase in velocity of a fluid results i
difference in speeds of the two parts of the fluid, therefore, creates a pressure diffe
force called upthrust.



If the foil operates in air, it's called an aerofoil, more commonly known as a
wing. If it operates in water, it's called a hydrofoil.

Boats using hydrofoils are uncommon but do exist. Their main purpose is to create upthrust from the flowing water, pushing the boat up and out of the water, reducing friction between the boat and water, allowing the boat to reach much higher speeds.

Comprehension questions

1. Name the five equations that can describe the dynamical evolution of a fluid.
2. Write down an equation that can be used to calculate the Reyno[illegible]ber of [illegible]
3. A rocket is part way through its launch at an altitude of 28 [illegible] de[illegible]ity of a [illegible] 2.46×10^{-2} kg m^{-3} and the rocket is travelling a[illegible] 1.8 [illegible]m s^{-}[illegible]e rocket has a [illegible] and a drag coefficient of 0.15, what is th[illegible]ce [illegible]g on the rocket at thi[illegible]
4. Describe how a foil produces [illegible] whe[illegible] s[illegible]bjected to a flowing fluid.

Discussion

[illegible]e i[illegible]ce of funding research into chaotic systems, such as fluids, if th[illegible] [illegible]getting an exact solution to their behaviour.

Extension

Foils aren't just used as wings for planes or as a source of upthrust for hydrofoil bo[illegible] other use of foils and present your findings as a factsheet about the application

Energy Storage

4.2 Energy, power and resistance

Keywords	
Generator	A device that turns kinetic ener[illegible] of a turbine, i[illegible] energy
Inertia	The willingne[illegible] remain in motion if in motion o[illegible]
Charge	The [illegible] of an object caused by an imbalance o[illegible]

[illegible]g e[illegible] technological challenge with well-established solutions, but [illegible] right time is another challenge in itself. Storage solutions for energy [illegible] basis behind **capacitors** that are vital to digital circuits, as in computers, [illegible] such as **batteries**. This article will talk through the various ways energy is stored.

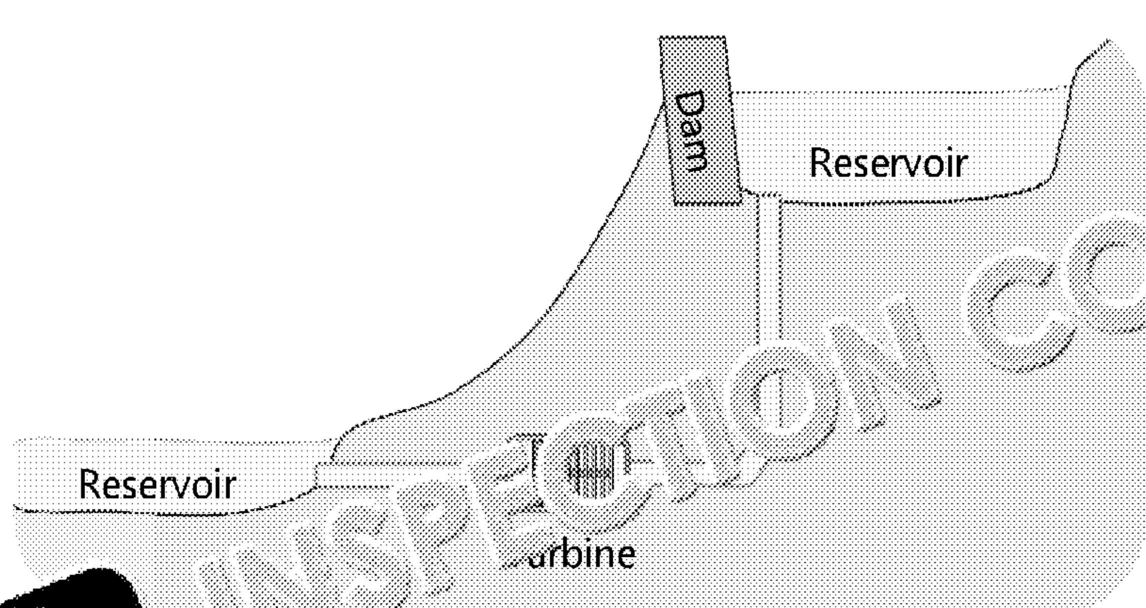
As society moves towards renewable sources which aren't as damaging to the envi[illegible] resources, the problem may not be generating energy, but storing it. Solar panels [illegible] during the day, but what happens at night? What happens to wind farms when it [illegible] windy for the wind turbines to function safely)? And with climate change and huma[illegible] rivers, not even hydroelectric power might be reliable.

Energy storage in the national grid

Modern life has become dependent on a constant power suppl[illegible] Without this, our technological infrastructure would powe[illegible] dow[illegible] reverting us back to the pre-industrial era. Po[illegible] constantly running to meet demand. [illegible] demand for power varies throughout the [illegible] depe[illegible] many factors. In the UK, it is the job [illegible] to make sure there is enough pow[illegible] of the time. Any excess power [illegible]ld c[illegible] countries, although this is difficult. Ideally, [illegible]l grid will store the excess energy to be used at a later [illegible] demand is high. The demand of the national grid tends to follow a predictable pattern each day, with exceptions such as TV pickup.

When a large n[illegible] same program[illegible] Cup final, Prin[illegible] crucial episode[illegible] end for every[illegible] people will go [illegible] resulting in a s[illegible] called TV pick[illegible] demand by up[illegible]

Gas power stations are the quickest type to react, yet still take up to an hour to fully turn on. Therefore, storage solutions are needed that have a large capacity, but can also be quick to respond.



Total p[illegible] during

[illegible] is **pumped storage**: a reservoir of water is held up high, and when power is needed, this water is released through a turbine and into a lower reservoir. The reservoir has a large gravitational store which

decreases as electricity is generated. The driven turbine generates electricity that c
Any excess power from the grid can be used to pump the water from the lower rese
reservoir, storing the energy for future use.

The Ffestiniog power station in north-west Wales is a pumped storage hydroelectric
fastest-responding power stations in the world, being able to generate 360 MW of
demand.

Pumped storage power stations can meet the response times and capacity requirem
national grid; however, they are not that efficient. The Ffestiniog power station uses
water back up to the higher reservoir than it generates when the water falls.

Other ways to store energy. One such method is thermal energy storage w
thermal energy in media such as water or molten salts. These can hold energ
and is usually used in conjunction with solar power generation to spread out the pow

Flywheels

A flywheel is essentially a large disc with the majority of its mass concentrated on its outermost section. The disc is rotated by a driving shaft, say from a turbine, storing the energy as rotational kinetic energy. Due to the conservation of angular momentum, the flywheel will continue to rotate, only losing a little energy due to frictional forces. The energy can be withdrawn through the rotating shaft when needed, reducing the angular speed of the flywheel. The kinetic energy stored in a flywheel is given by:

$$E = \frac{1}{2}I\omega^2$$

I =

E – Energy
I – Moment of inertia
ω – angular speed
m – mass in outermost section of flywheel

Flywheels are commonly used in mechanical applications such as steam or petrol engines. The energy generated by such engines comes in bursts with periods of no power. The flywheel stores and releases the generated energy, spreading the power out during each cycle. This makes the overall power output of the engine smoother and easier to apply.

Batteries

A battery is a device that stores energy. So technically, the flywheel and pumped st types of batteries; they store mechanical and gravitational energy. The t 'batter electrical type.

An electrical battery is a chemical store of energy. Batteries c two types:

1. **Primary** – the battery is produced ... it can immediately output discarded once it's complet...
2. **Secondary** – the b... charged before its first use. These batter their elect... rea...ns are reversible.

... batteries are the most common as they are much more efficient. ... the energy density of a battery, the better it is. This is why **li...-ion batteries** are the most common type of electrochemical batteries currently available.

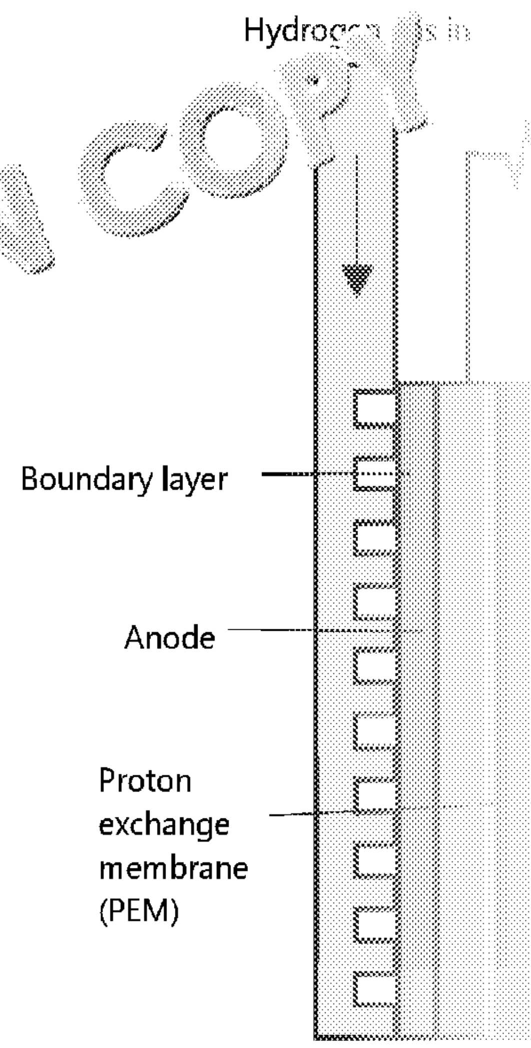
A lithium-ion cell is constructed of an anode (positive terminal) and cathode (negative terminal) suspended in salt solution containing lithium ions (called the electrolyte). When the anode and cathode are connected via a circuit, the lithium ions will be attracted to the cathode, causing the cathode to become positively charged. Electrons then flow through the external circuit to this positive cathode until the battery is completely discharged. Applying a current in the reverse direction to the cell (electrons flow into anode) causes the lithium ions to flow back to the anode, charging the cell once more.

Battery technology has drastically improved ... years, resulting in applications portable batteries and power grid st... becoming ever more popular. In the UK developing battery storage ...ructu... under the enhanced frequency response contract was to build ... that can store energy for short periods of tim supply the n... he first completed project was E.ON's Blackburn Meadow ...tte... can supply the national grid with power in less than a second ...umped storage solutions. Many of these projects have caused the nation ...rease, rising from 2.5 GW in early 2017 to 8 GW at the end of 2017.

The future of batteries will see the incorporation of metamaterials such as graphen at Harvard University have developed an electrochemical system that can store larg between 2D layers of graphene. The graphene provides a low-resistance pathway f the anode to cathode, increasing the ion capacity of the battery; therefore, increasin charge capacity of the battery (**https://phys.org/news/2018-06-physics-batteries** other ions, such as magnesium ions, could also be the future of batteries. Magnesi of research because they have a theoretical energy density by volume that's 50 % g

Hydrogen fuel cells

Standard combustion engines use fossil fuels and release harmful gases into the environment. An alternative to fossil fuels is **hydrogen fuel cells**. The fuel is simply hydrogen gas, H_2 that mixes with oxygen from the air. The result is generated electricity, some dissipated heat, and water vapour; nothing harmful there.



A **catalyst** in the ... layer next to the ... use ... molecules to split into ... gen ions (two protons) and two ... The **proton exchange membrane (PEM)** only allows protons (i.e. hydrogen ions) to pass through, and not electrons. The ions pass through the PEM to the cathode (to react with the oxygen atoms), making the cathode positively charged (similar to a lithium cell). Electrons are attracted to flow around the external circuit, doing work as they do, and then neutralise the hydrogen ions, which react with oxygen atoms to form water vapour.

Hydrogen fuel cells are much more efficient than standard combustion engines and the production of hydrogen gas is less harmful compared to extracting fossil fuels. However, the current ... seems to favour charging and s... power electrical vehicles, rather than ... hydrogen fuels cells.

Capacitors

... r is a quick way to store electrical energy. Two electrodes are separated i... ...ctric field for a short time. The capacitor is charged when a potential dif... until the capacitor reaches a critical point, where it then discharges. The capacitanc... charge it can hold) is measured in farads, F, and a typical capacitor has a capacitanc... charge for several seconds.

Supercapacitors have a much higher capacitance (10 F to 100 F) compared to typica... can hold charge for much longer, too, bridging the temporal gap between capacitor... in quick charge/discharge applications, such as regenerative braking or static rando...

Computers use **random access memory (RAM)** to temporarily store information while running programs or calculations, similar to short-term memory in humans. Most RAM in computers will be **dynamic (DRAM)** which uses normal capacitors. Du... short discharge time of these capacitors, ... information stored would ... quickly ... t. Therefore, DRAM uses a separate ... refresh circuit to keep ... information ... **static random access** ... (SRAM) instead uses supercapacitors which ... information for much longer. A separate ... circuit is, therefore, not needed, which makes the RAM much faster to respond.

The principle of rege... the kinetic energy of ... d... rather than usi... ...ssipat... this kinetic e... then be used to pow... overall efficiency of th... the electric motors o... absorbing the kinetic... generating power tha... system. **Kinetic** energ... also installed in cars a... Formula One in 2009... stored in a flywheel o... discharged in later ac...

Comprehension questions

1. Other than pumped storage, name one way energy is stored and later used by
2. A flywheel has a radius of 25 cm and a mass in the outermost re... 13.5 kg ... the flywheel if it's spun to an angular speed of 283 rad s^{-1}...
3. Describe how flywheels aid petrol and steam engine...
4. Describe the difference between DRAM ... M.

Discussion

A private company wants to generate its own electricity on-site to completely disco... from the ... It will generate its power using an array of solar panels and a ... The power output from these sources varies a lot and doesn't match their ... that are available to the company and decide which solution is the best.

Extension

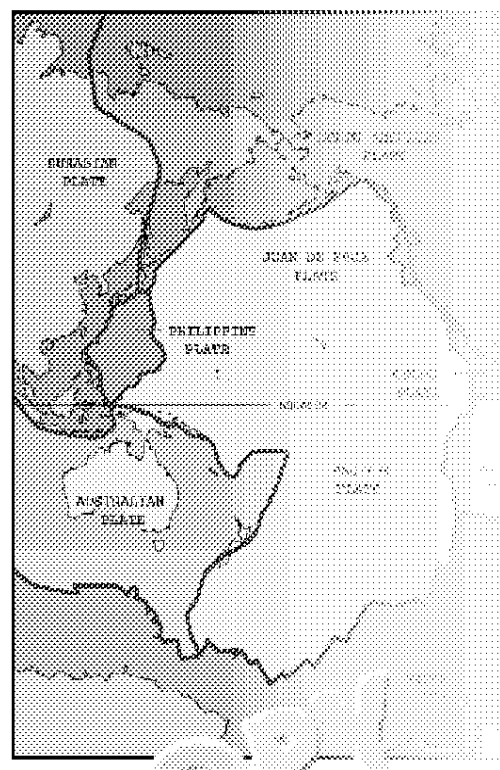
Prepare a two-minute presentation to explain what a hydrogen fuel cell is and how ... classmates. To aid with the explanation, draw a diagram of a hydrogen fuel cell and

Earthquakes: Shaking Thin

4.4 Waves

Keywords	
Seismic waves	Waves that travel through ...
Attenuation	The reduction in ... wave as it travels through a
Plasma	The fourth ... where atoms are partially or fully i

Earth is still ... of molten rock from when ... billion years ago. The outer ... ball has cooled due to its exposure to ... space.



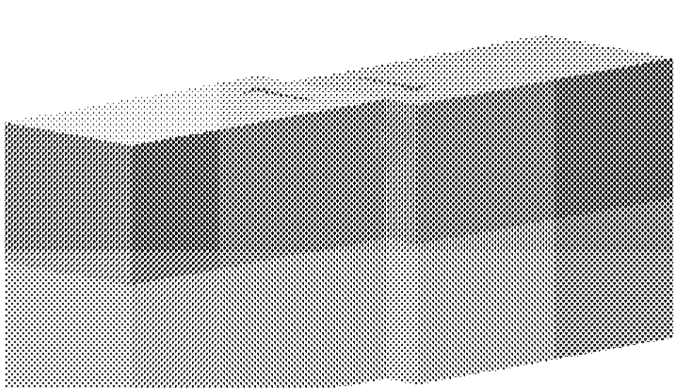
This outer layer is split into plates (like puzzle pieces) that move around due to convection currents in the mantle – a thick layer of magma around the Earth's core. These plates are budged up tightly to one another, with high friction coefficients. When the stress becomes too high for the plate boundary (the limit known as the local strength) the plates slip causing a shockwave of vibrations to propagate through the plates and molten rock. This is called an earthquake.

Earth's crust is split into eight major plates with a few smaller ... The way plates be categorised into three ways:

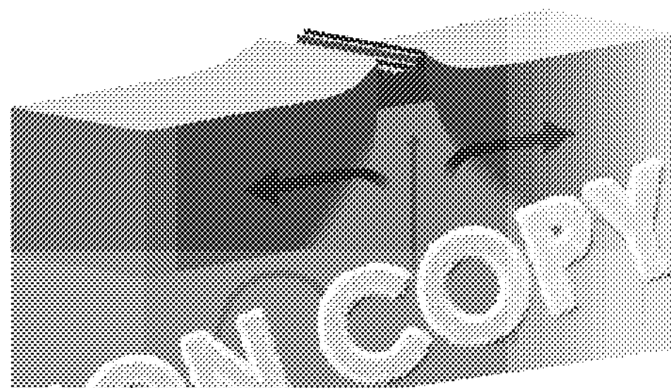
A **transform boundary** is ... by two plates moving in different directions relati are moving horizontally, ... boundary is known as a transform fault. A common ex San ... the west coast of America. These faults can result in very

... **boundaries** can produce earthquakes, although they tend to be small ar ... reach the surface and cool, creating volcanoes and islands if positioned i was formed around 16 million years ago).

Convergent boundaries result in a less dense plate sliding on top of the more den dense plate down into the mantle. This can lead to the construction of mountain r also to strong earthquakes.



1. Transform bound...



2. Divergent boundary

Seismic waves

Earthquakes release a lot of energy. The size of an earthquake is commonly measured using the Richter scale, although this doesn't distinguish large earthquakes from one another.

A modern replacement of the Richter scale is the moment magnitude scale (MMS), used for earthquakes of more than 6.5 on the Richter scale. An earthquake in 1994 in Northridge, California, measured 6.4 on the Richter scale and 6.7 on the moment magnitude scale. A lower bound for the energy released can be calculated from the MMS, M_W, as:

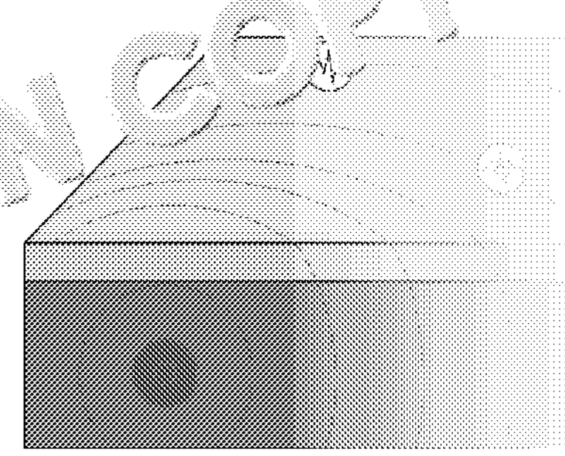
... + 11. ...

which for the Northridge earthquake is an energy of:

$E > 2.0 \times 10^{21}$ J

The largest bomb ever denoted by humans was the Tsar Bomba in 1961. It released ... earthquake in California released more than 9500 times the energy of the Tsar Bom... Richter scale, a medium-level earthquake.

Most of this energy is used to deform rocks or cause heating near the epicentre ... some is radiated away from the epicentre as seismic waves. In our 3D world this en... directions. However, the position of the epicentre means Earth's surface ... much cl... another. This part of the surface will, therefore, receive more energy and much more quickly after the earthquake has occurred.



Energy is radiated away in the form of a ... These seismic waves can ... into three parts, each arriving at a detection point at different ... to ... They are:

1. P-waves
2. ...
3. Surface waves (also known as L-waves)

The P-waves (stands for primary waves) are longitudinal, like sound waves, and trav... around 10 km/s.

S-waves (stands for secondary waves), on the other hand, are transverse and travel...

Finally, surface waves carry the majority of the energy (so cause the most destructio... surface (as the name suggests), so have further to travel to a detection point.

The different arrival times of the parts of a seismic wave can be used to determine ... is from the epicentre. Using many detections sites, the position ... of the ep...

Seismographs

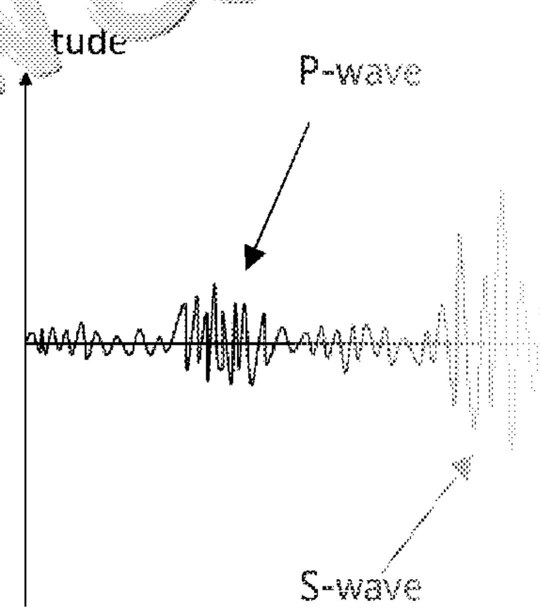
Detection points dotted around the globe use **seismographs** to determine any motion in the ground. The basic principle of a seismograph is to use a pin point that moves across paper due to some motion.

The simple seismograph shown on the right will [illegible] movement in the vertical direction, moving the heavy weight up and down relative to the paper, drawing these oscillations onto the moving paper. By having three of these oriented for each [illegible], the 3D motion of the ground at a detection point can be [illegible]. Modern seismographs use digital [illegible] to detect [illegible], providing much more accurate data.

[illegible] seismograph recorded during an earthquake is shown below. The first pulse is the arrival of the P-waves, then come the S-waves, and finally the majority of the energy of the earthquake hits the detection point as the surface waves.

Waves are attenuated (lose energy) when they travel through a medium. Seismic waves are no different. The further a detection point is from the epicentre, the smaller the amplitude of the measured waves. By comparing this distance to other seismographs, the positon of the epicentre can be determined.

Replacing the seismograph



Nowadays, seismographs are digital and much more sensitive than the mechanical apparatus described above. However, [illegible] are not the only method [illegible] earthquakes. The [illegible] tectonic plates [illegible] extremely low [illegible] (ELF) electromagnetic radiation. [illegible] are also hot, so emit infrared (IR) radiation, just like any black body.

Therefore, the future of predicting earthquakes will see an array of satellites constantly orbiting and monitoring tectonic plates in the ELF and IR parts of the electromagnetic spectrum. Signatures in these parts of the spectrum that lead to earthquakes can be used to predict future earthquakes weeks in advance, as oppos[illegible] millions of lives. To do this, though, the equipment must be extremely sensitive and

Sun surfing

Helioseismology is the study of waves that propagate through the Sun. These wave
to tectonic plates, but by the complex temperature and pressure oscill[illegible] in the r
a plasma, unlike the rocky Earth, so the waves propagate differ[illegible] th resear
applications in the containment of plasmas in fusion reac[illegible]rs a[illegible]d p[illegible]cting sola
communications here on Earth.

Waves travelling through the Su[illegible]sed into three types:

- **P-waves**
  Similar to th[illegible]s th[illegible] travel through Earth, these are fast longitudinal wa
  [illegible]Sun.
- **[illegible]ves**
  [illegible]aused by the gravity due to the mass of the Sun, these slower waves are foun
  They are analogous to the S-waves that travel through the Earth. As they occu
  observation of G-waves has been made, but their existence is implied by other
- **F-waves**
  Also known as surface gravity waves, these are transverse waves that propaga
  like water waves over the sea.

Comprehension questions

1. Name one example of a transform fault line.
2. What is the minimum energy released by an earthq[illegible] which [illegible]easured to
   moment scale?
3. What fact, other than the arrival ti[illegible] types of seismic waves, is us
   the epicentre of an earthq[illegible]
4. Describe the futur[illegible] prediction.

D[illegible]sic[illegible]

[illegible]ether it is more important to invest money into researching geoseismolo
th[illegible] the Earth) or helioseismology (study of waves through the Sun).

Extension

The Solar and Heliospheric Observatory (SOHO) satellite has been monitoring the S
years. Research this satellite and its findings and present your research as a fact she

.

Laser Focus

4.4.2 Electromagnetic waves

Keywords

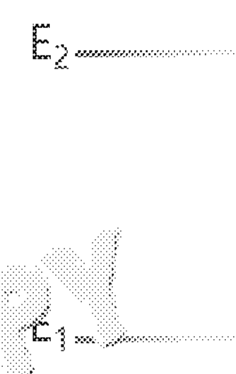
Ground state	The lowest possible en... particle. Note that th
Energy transition	The gain or lo... a particle, causing it to trans
Optical resonator	The ... light resonates and amplifies, pr

Fundamental principles

Each electron in an atom has an associated energy level. These energy levels are discrete. An electron is only allowed to have energies that correpsond to these ener... change energy level if it gains or loses energy. It can do this via three ways.

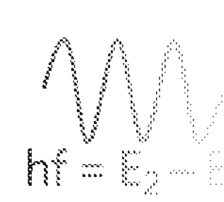
Spontaneous emission

An electron in an excited state (a higher energy level than normal) will eventually transition into its ground state. The average time it takes to do this is called the **damping time constant** and is typically a few nanoseconds. When the electron does decay to its lower energy level, it emits a photon with an energy equal to the difference in energy levels. The higher the excited energy level, the shorter the wavelength of the emitted photon. This emission of a photon is called **spontaneous emission**.



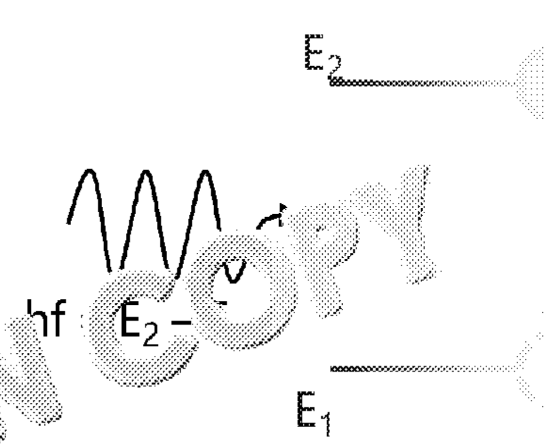
Absorption

As the name suggests, absorption is where an electron in a low energy state absorbs an incoming photon to transition to a higher state (the opposite of spontaneous emission). The incident photon must have the exact same energy as the energy difference between the low and high energy levels, otherwise the photon will just miss the electron without interacting with it.



Stimulated emission

Consider an electron in a high energy state, as for spontaneous emission. If an inci... equal to the energy transition ($E_2 - E_1$) comes along, the photon will interact with the electron, causing the electron to transition to the lower energy level. The change in energy causes a new photon to be emitted with an energy equal to the energy transition ($E_2 - E_1$). There are now two photons, each with an energy equal to the energy level transition ($E_2 - E_1$) that are in phase with each other. The first photon stimulated the emission of the second photon, hence the name stimulat...

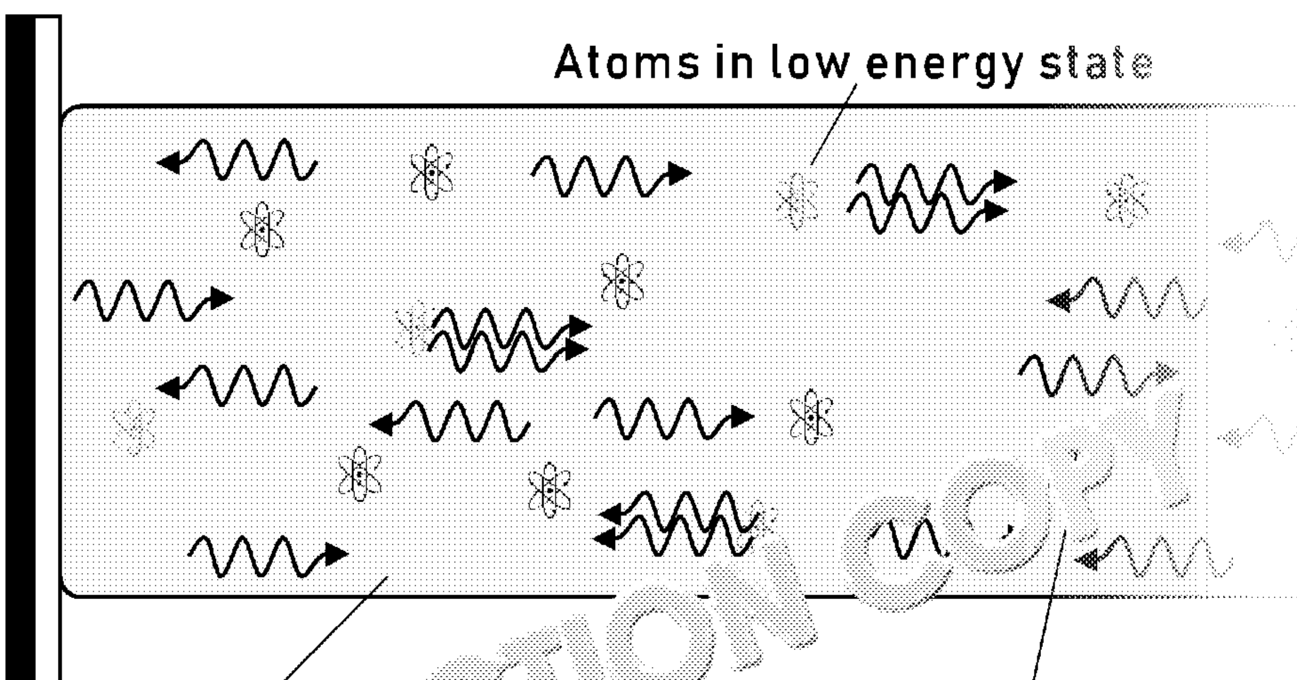


How a laser works

A laser uses the principle of stimulated emission to create many coherent photons o[illegible] frequency. The photons are generated using a **gain medium**. This a m[illegible]l in an[illegible] plasma) that is excited by either external light sources (**optical** [illegible]) or an ext[illegible] **pumping**).

The emission of one photon (via spont[illegible]) from one of the excited ato[illegible] start a chain reaction of photon [illegible] stimulated emission. If the number o[illegible] larger than the number [illegible] the lower energy state, the rate of stimulated em[illegible] absorption, res[illegible] net [illegible] of photons travelling through the gain medium

[illegible]er o[illegible] generated photons can be further increased by placing the gain me[illegible] [illegible] called an optical cavity). This is basically adding two mirrors either end[illegible] c[illegible] backwards and forwards through the gain medium, stimulating the emissio[illegible]



Thi[illegible]ess [illegible] light inside the gain medium. Releasing this light throug[illegible] [illegible]am [illegible] coherent light, useful in many applications. This device is called a L[illegible] **E**mission of **R**adiation, or LASER for short.

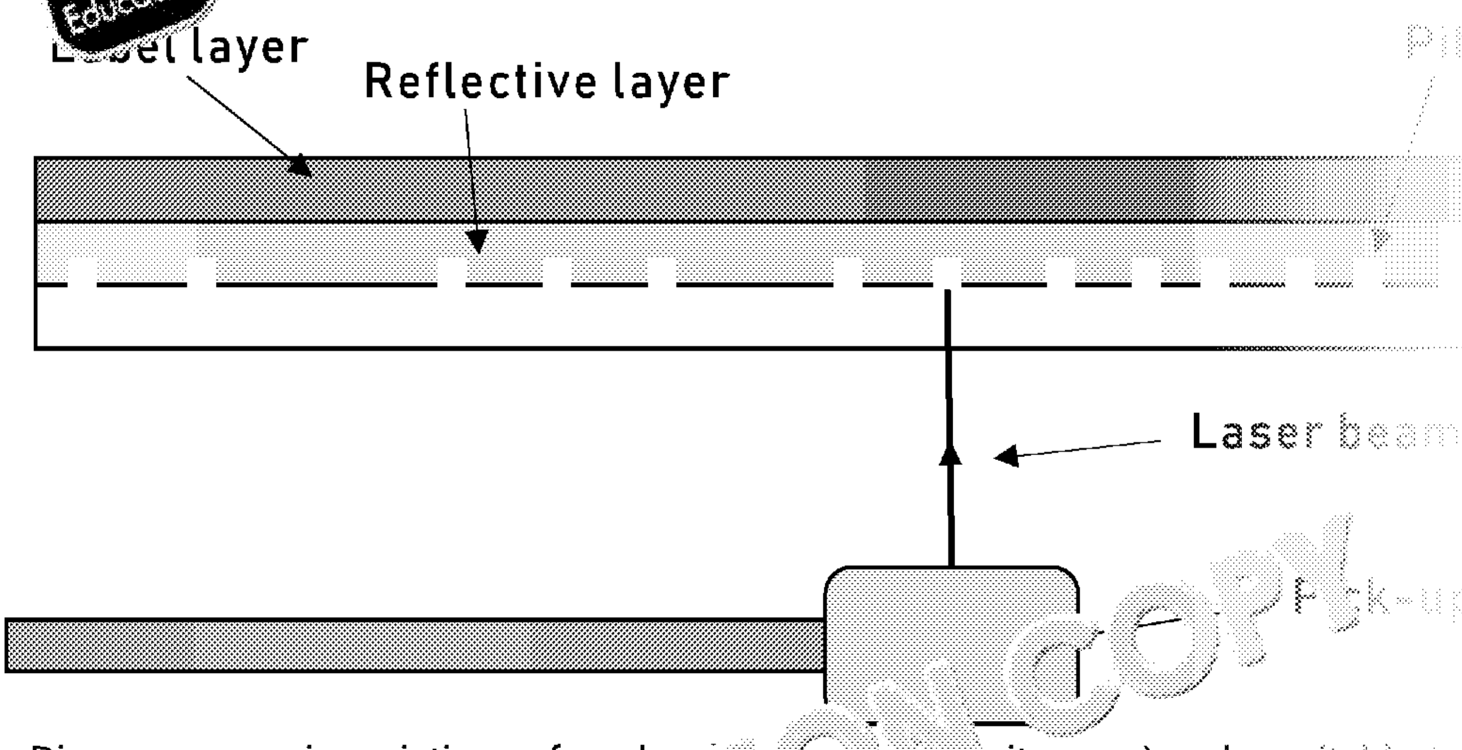
Applications of lasers

Lasers have a huge number of applications, from barcode scanners and optical disc[illegible] and cutting-edge research.

Optical disc drives

An optical disc drive is a common method of storing data. Information is stored on
The discs used are split into three types: compact discs (CDs), digital versatile discs (
types are ordered in increasing storage capacity but are also ordered in increasing

The basic optical drive is made of a **pick-up head (PUH)** that can move along the
servomechanism. Information is stored on the disc as a series of 'pits' in one line s
The PUH usually contains a semiconductor laser, a lens for focusing the laser light, a
detect the reflected light from the disc. The lens also has a servomechanism to adj
laser light is focused to a small spot on the disc.



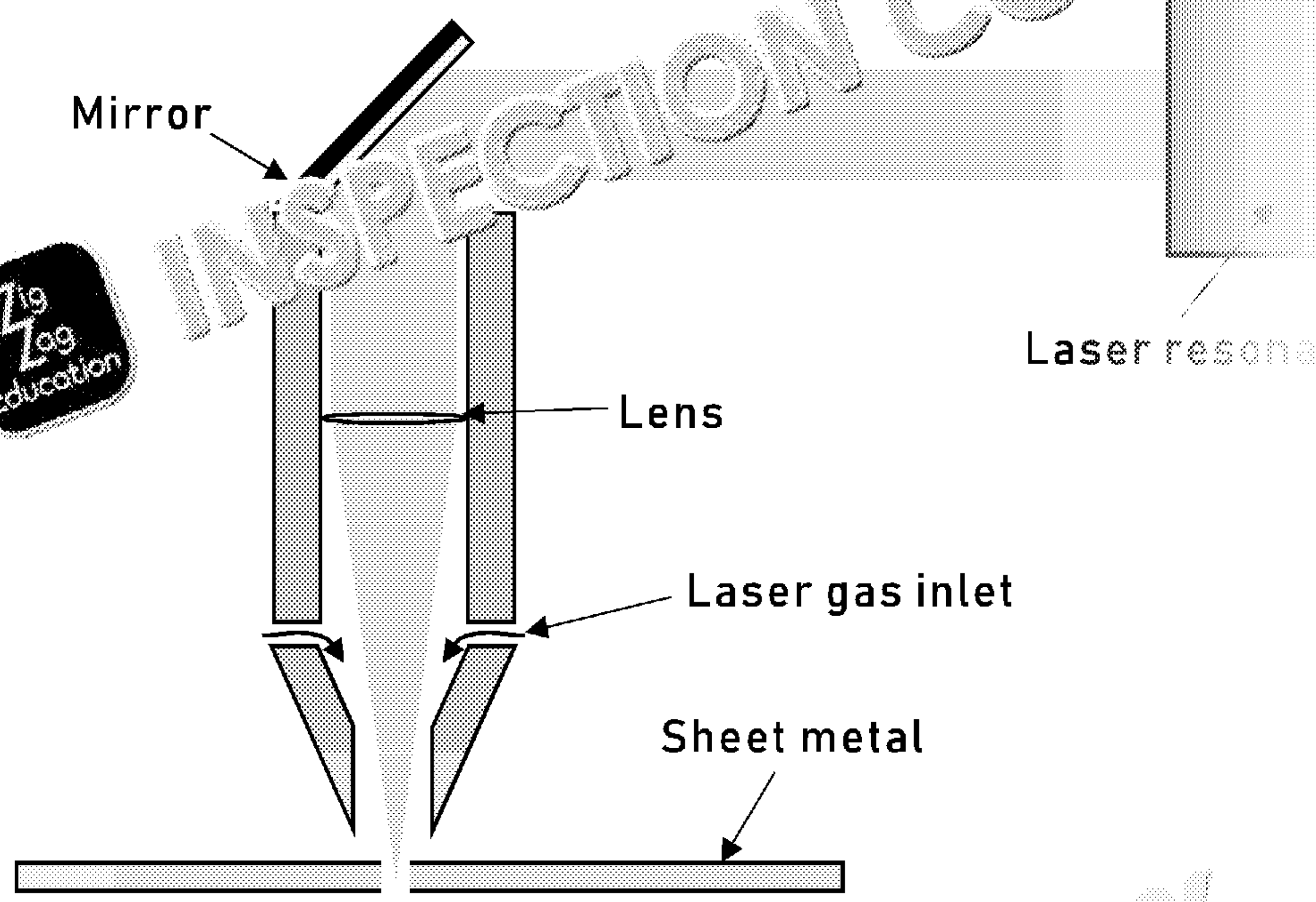
Discs can come in variations of read-only, recordable (write once) and rewritable (
the read-only disc (ROM) which comes with pre-written data, such as a music CD.

The data is stored as a series of 'pits' and 'raises' in a reflective layer, similar to
around 1/5 the wavelength of the laser light used. This m
interferes with the incoming laser light. The reduction in amplitude o
diodes, recording the hard-coded information electronically.

To increase the data storage capacity of a disc, the distance between adjacent pits
the pits are read correctly and the laser dot doesn't spread over multiple pits, the w
be decreased. This is why the older CDs use infrared light (λ = 780 nm) whereas the
light (λ = 405 nm), hence the name Blu-ray.

Laser cutters

Powerful lasers can be used to cut through materials such as stainless steel or alum head can be moved using servomotors, allowing intricate designs to be ... nto the cleanly and smoothly cuts the metal in comparison to conventi... ng methods



The most common laser type used in laser cutting is the C... er, ... h uses CO... emits infrared light with a wavelength of about 1 ... m. Th... em... beam has a diam reflected off mirrors towards the sheet m...t ... hrough a lens. The lens focu point, increasing the intensity of ... his also allows a small amount of the process efficient co... co...tional cutting techniques.

De... ng ... being cut, a gas is injected around the point of cutting ... use... r mild steel, which is cut using an oxygen-fuelled burning process. ...ke stainless steel and aluminium, which have lower melting points, so the

Comprehension questions

1. Describe how light is amplified in a gain medium.
2. What is the approximate ratio between the wavelength of light used by a PUH created in a disc?
3. Why is a gas used in a laser cutter?

Discussion

With the rise of solid state drives (SSDs) which use microchips (which ... ter to ... discs to store information, discuss the future of optical disc dri... ard discs.

Extension

Lasers come in a variety of p... ratin... owerful lasers can be dangerous, especi someone's eye. For ... aser is categorised into a class; the higher the aroun... that ... the laser safety standards and present your findings as a

Optical Fibres

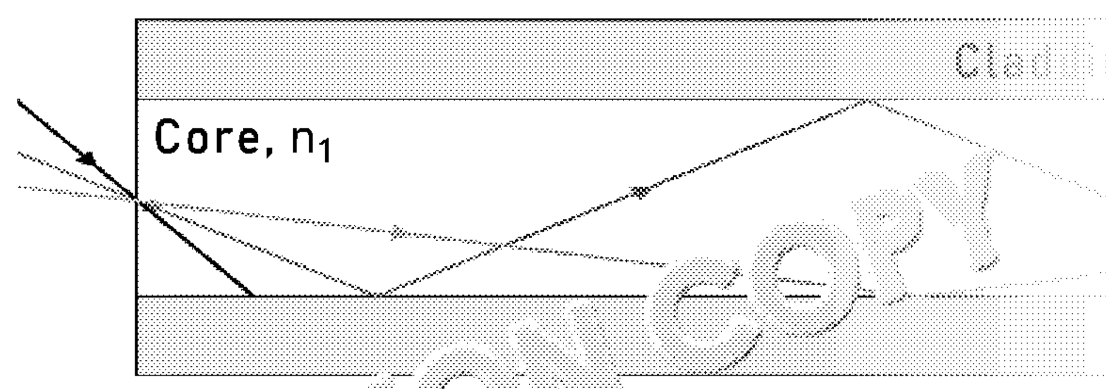
4.4.2 Electromagnetic waves

Keywords	
Cladding	The outer material of a fibre-optic cable with the lower refracti…
Core	The inner material of a fibre-optic cable, with the higher refracti…
Dispersion	The spreading out of different parts of a signal as it propagates

Optical fibres … waveguide that transmit light in a controlled manner ov… … signals resulting in fast (at light speed) data connections betw…

How they work

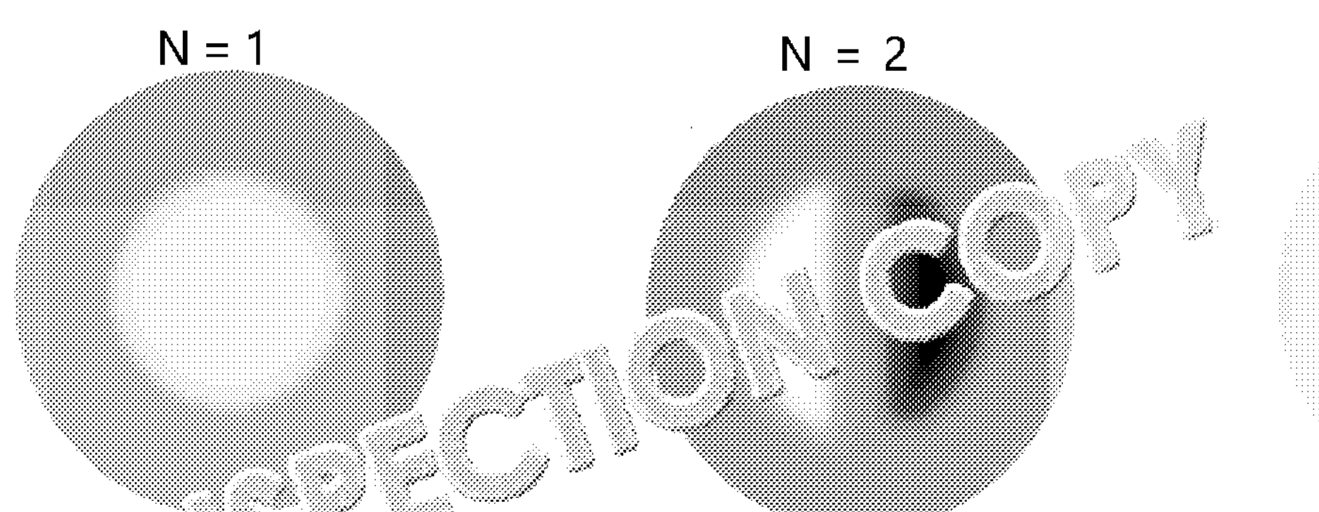
The basic fibre is constructed with a core encased in a cladding. The core has a hig… cladding ($n_1 > n_2$), so a light ray that is incident at the boundary between the two m… critical angle will be totally reflected. This principle is called total internal reflection… waveguides such as fibre-optic cables.



A waveguide will have a number of modes depending on its dimensions and refrac… is an electromagnetic … that propagates through the waveguide without chang… a waveguide … constructed with different amounts of the waveguide's modes… principle … maths where you can expand trigonometric functions such as

$$\sin(x) = x - \frac{1}{6}x^3 + \frac{1}{120}x^5 - \frac{1}{5040}x^7 + \dots$$

In this analogy, the powers of x are the different modes and the coefficients in fron… mode has to the overall function ($\sin x$). The first three modes ($N = 1,2,3$) for a circ…



… white and black represent positive and negative amplitudes of the waveguid… a waveguide can hold is finite, typically only a few. A waveguide can also be design… the fundamental mode ($N = 1$) can propagate through it with all others being abso… removes the effect of dispersion but is also expensive to manufacture.

Dispersion

A pulse of light can be made up of many different components that each travel at d[illegible] travels at the same speed through a vacuum, different wavelengths tra[illegible] differe[illegible] even for a single wavelength in a medium, depending on the a[illegible] passes[illegible] have a shorter path length, meaning it will travel a differe[illegible] and take more[illegible] at the same speed.

If the length of the fibre-optic ca[illegible]gh, these different components co[illegible] times, which could inter[illegible] he [illegible]ding of the signal. There are three types of[illegible]

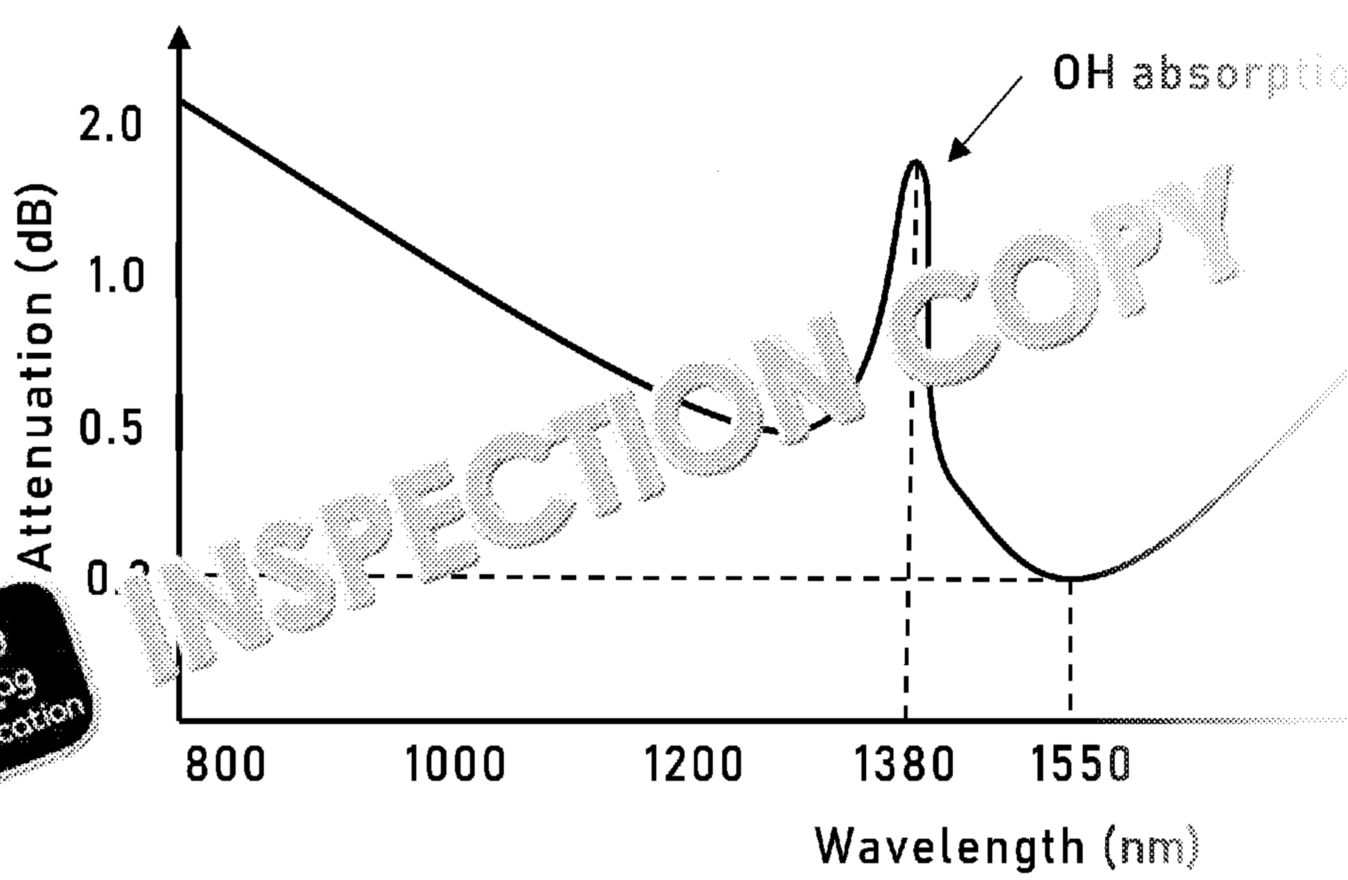
1. **[illegible]rm[illegible]n**: Different modes in a multi-mode fibre have different [illegible] fi[illegible] were invented to remove this type of dispersion. Single-mode fib[illegible] [illegible]er, so the cheaper multi-mode fibres are used for short-distance transmi[illegible]
2. **[illegible]omatic dispersion**: Different frequencies of light (i.e. different colours, alth[illegible] radiation outside the visible part of the spectrum) travel at different speeds. T[illegible] subdivided into two other types of dispersion:
   - Material dispersion: The refractive index of a material may vary depending [illegible] travelling through it.
   - Waveguide dispersion: The way the materials have been used to make the[illegible] frequency dependence on the refractive index, even though the materials [illegible] dependence.

   A pulse of light will have a range of frequencies when generated, meaning the[illegible] propagation. For a high density of information, as in today's sig[illegible] smissio[illegible] which becomes a problem. A regenerator is positione[illegible] m i[illegible]ervals a[illegible] signal and remove this chromatic dispersive eff[illegible]t. [illegible]so, [illegible]aser light (cohe[illegible] frequency) reduces the effect of this di[illegible]
3. **Polarisation mode dispersi[illegible]** [illegible]sations of modes can also trave[illegible] the light before it ent[illegible] fibre [illegible]emove this effect.

Attenuation

[illegible]l is completely transparent to all wavelengths of light. The atoms of the[illegible] w[illegible]ngths, exciting their electrons to higher energy levels. Combine this with the[illegible] will be exempt from impurities, which results in the absorption of some light propa[illegible]

The longer the signal travels down a fibre, the more light is absorbed. The measure[illegible] light is called its attenuation and is measured in decibels, dB. Below is the absorpti[illegible] common material in fibre optics.



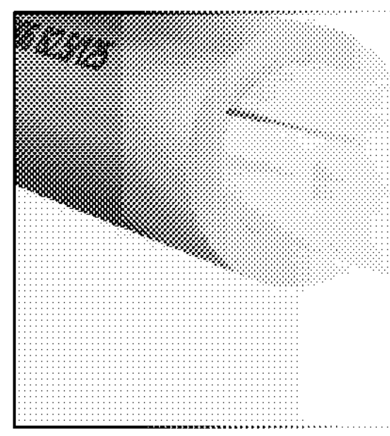
From the attenuation spectrum of silica it can be seen that the wavelengths of 1550 the spectrum) experience the lowest attenuation, which is why this wavelength is us communications. The peak at 1380 nm is caused by O–H bonds (oxygen and hydro This impurity is mainly water, which is why fibre-optic cables must be manufactured also why food, which contains water, heats up in a microwave.

Silica glass is typically used as both the core and cladding in optical fibres, with the small amount of material to slightly decrease its refractive index. Optical fibres wor the core and cladding are very similar, with a typical difference of less than 1 %.

Real-world fibre optics

Transatlantic cables

Optical fibres are used to transmit data between continents. For example, a transatlantic telecommunications cable (TAT) connects Europe to North America via a shielded optical fibre (see right). A network of these cables ensures large amounts of data can continuously be sent between the continents. Without them, we wouldn't be able to use websites based in America, or make phone calls to people across the pond.



These cables run along the sea bed, placed by a large boat that unreels them over t one coast to the other. A robot then moves across the sea floor (as it's too deep fo using water jets to dig a trench and lay the cable in. The cable must be able to with its environment.

The most common fault in TATs is a breakage, usually due to an anchor from a boat dragging and cutting the cable. To reduce the risk of this happening, cables are built with large amounts of shielding, as seen in the cross section of a cable above.

Endoscopes

A fibre can also transmit an image. This makes them very useful in medicine and industry because optical fibres are thin and can bend around corners without distorting the image (there is a limit to how much a fibre bends before the signal is distorted, however).

An endoscope is used in medicine to get a better look at something within the body. It's made of two fibre-optic cables that both join to the capturing lens. The first fibre-optic cable is used to supply a light source. Light travels down this cable into the body, reflects off the part of the body that is to be looked at, and then is reflected into the second fibre-optic cable. This image is sent through the second cable up to the doctor's eye.

Optical fibres are also used in cutting-edge research into stimulating synapses. A synapse is the tiny gap between two neurones in the cells of the nervous system (including the brain) that transmit signals as electrical impulses. By manually stimulating synapses, therapies for diseases like motor neurone disease can be researched and developed. Optical fibres that use infrared radiation for stimulation have the advantage of sending a precise impulse at the synapse without physical contact (no inflammation from injury, etc.); however, it can cause heating in the tissue.

Comprehension questions

1. Draw an image that represents the second mode of an optical fibre.
2. What type of fibre-optic cable is used for short distance transmission, and why
3. Describe one type of dispersion.
4. What wavelength of light is typically used in fibre-optic cables made of silica, a

Discussion

Communication satellites are becoming ever more popular and it is predicted that t telecommunication cables we currently use today. The connection speeds will be ob currently outperformed by TATs. Discuss the advantages and disadvantages of communication satellites.

Extension

A photonic crystal fibre is created using only one material. An array of 'holes' acts as whereas the centre is purely the material used and acts like the core. Research phot report on the research currently being done on them.

4.4.2 Electromagnetic waves

Keywords

Photon	An elementary particle that is a quantum excitation of the electr
Focal length	The distance between a lens or parabolic mirror and its point of
Wave function	The property of a quantum particle that describes its position wi

Light is made of excitations in the electromagnetic field called photons. These p interact via effects such as absorption, transmission and reflection.

is reflected off an object and enters our eye, our brain then determines object. The object will absorb and reflect certain wavelengths by different amounts as the colour of the object.

However, light doesn't interact with everything. This could be because the energy energy of incident photons, or the object is much smaller than the wavelength of th interactions are very rare. So how do we image things which don't interact with lig

Schlieren photography

Air doesn't interact with light very much. To see any sort of effect, the light must pass through huge amounts of air, like the scattering of blue light as it propagates through kilometres of our atmosphere (and hence the sky looks blue). But air has some density and light propagates through materials of different densities at different speeds. Materials of higher density, such as water, slow down light compared to materials of lower density such as air.

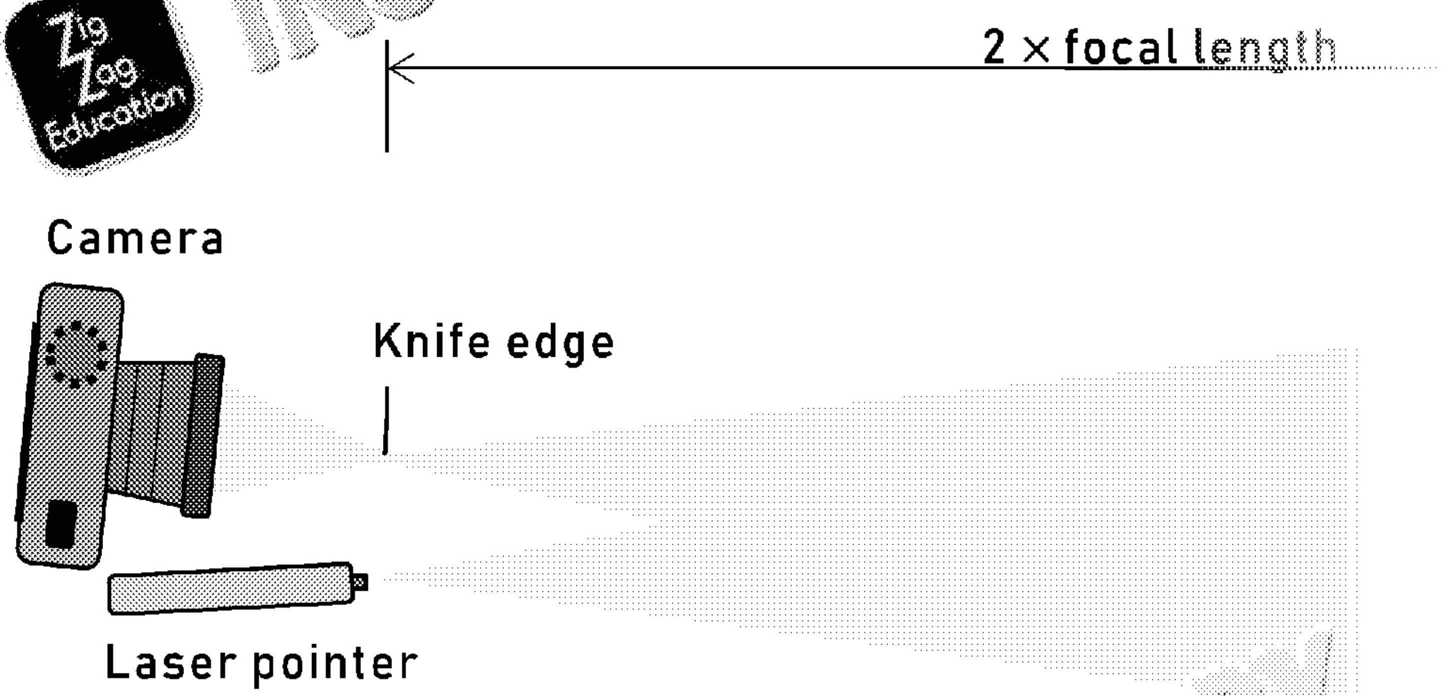
The density of air is not constant; it can vary due to turbulences such as the wind, o ess sound. In 1864, August Toepler, a German physicist, was supersonic motion (faster than the speed of sound). The resulting motion intense pressure waves in the air.

To see these pressure waves, August Toepler developed an imaging technique calle ('Schlieren' means streak in German. This technique amplifies the refraction of light of varying density, resulting in images like the image of a flammable liquid set alight hot, less dense air is seen to rise above the cool, denser air to the sides, similar to th

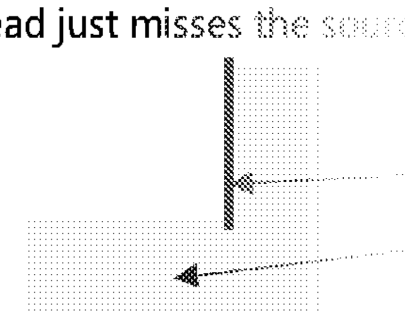
How does it work?

There are a number of ways to set up a schlieren imaging system, the most commo below. You will need a high-definition camera, a point source of light such as a las and a parabolic mirror.

- Set up the camera and light source close together, both pointing in the same d
- Then position the parabolic mirror at twice the focal length away from the came on the diagram below.
- Next, turn the light on and place the filter or knife edge to cut the refle the camera. You may need to move the camera back a little.



- The point source light is reflected by the parabolic mirror and is focused back t
- Angle the mirror slightly a little so this focused light instead just misses the sourc camera.
- The light should then pass a knife edge or the edge of a colour filter. This edge will block some light going in one direction, but allowing light in a slightly different direction to pass on (see the diagram on the right).



Remember that any variation in density in the air near the mirror will cause reflected Therefore, some densities of air, say low density, will be blocked by the knife / by th will pass through. This gives our final image some contrast so we see the different

A small point source of light is used, so any change in direction of the light, due to variations in air density, will cause the focused light to miss the normal focal point a image in the camera showing the slight variations in air density ... by th

Schlieren photography is used a lot in aerospace and aeronautical engineering. Co behaviour observed in wind tunnels, and designers build a picture of how aero photography is not unique to variations in density, however; it can be used to im as the temperature diffusing through a tank of water (remember the hotter a fluid is

Probing the nanoscale

How do you image something that is too small to interact with the light, such as an something smaller than an atom, like an electron, or use the interaction ... the atom two methods that are used in scanning tunnelling microscopy (...) ... atomic for

Scanning tunnelling mic... (STM)

Scanning tunnelling microsc... (STM) ... advantage of quantum tunnelling. Th a particle to tunnel ... energy barrier because its wave function sp

... fur... particle is a quantum description of the particle and is relat a particular position. The probability of finding a particle far away from t ...ility of a particle tunnelling through a potential barrier is small, but it isn

An STM uses a tungsten tip that is close, but not 'touching' the surface of a material that is to be imaged. The word touching doesn't mean much here, because we are talking about the interactions of atoms which never actually touch, just interact via potential fields.

A potential difference is set up between the tip and the material. This decreases the energy barrier between the tip and surface, increasing the tunnelling current that occurs. The tip and surface are connected to a series of actuators (precision motors) and a computer. These work together to keep the tunnelling current, the number of electrons that tunnel from ... to the surface (or vice versa), constant.

The tunnelling current is directly proportion... sta... between the tip and surface, so if the surface h... in ... tip will raise and lower over the bump. This mover... the ... recorded by the computer and eventually enough ... generate an image of the topology of the ma surf...

... is the image of a molecular structure shown on the right. To give you a t... of measurements an STM makes, if the STM were the size of the Eiffel tow variations in height due to the 'bumps' of each atom would be around 2 cm!

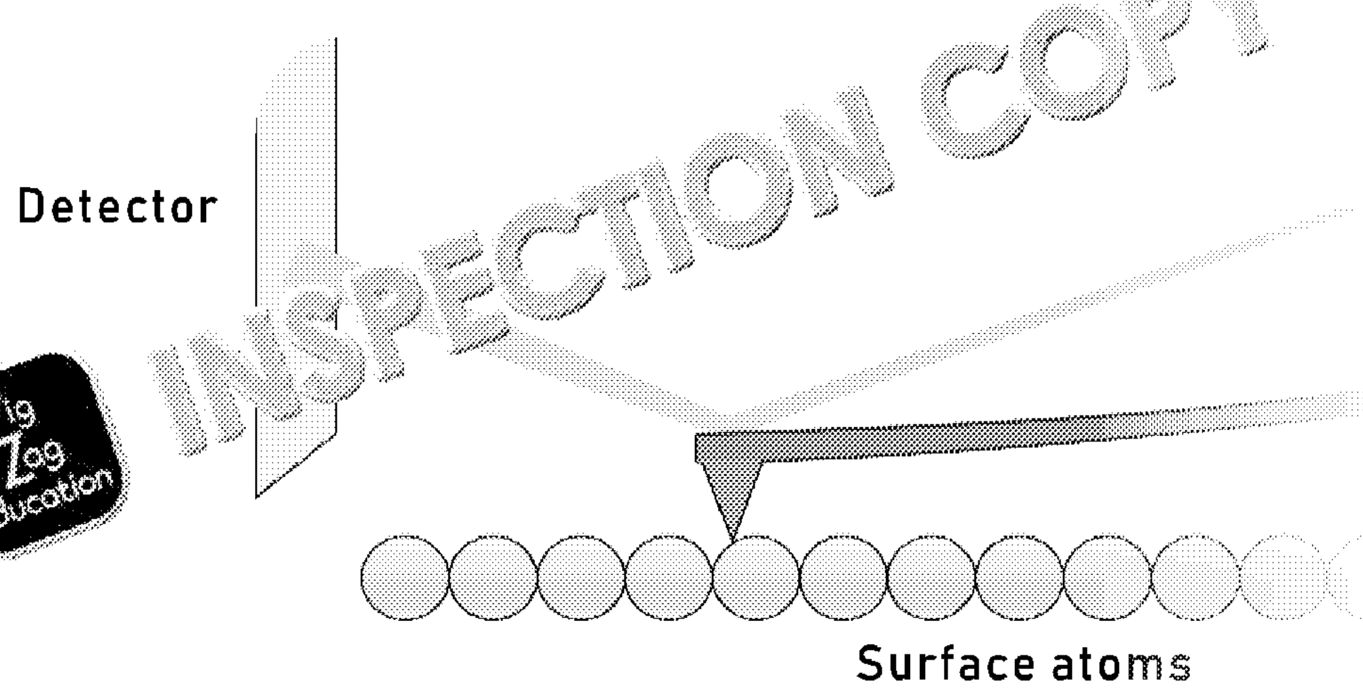
STMs can also be used to manipulate atoms. By allowing the tunnelling current to to a particular atom, the tunnelling current increases. This results in an attractive fo tip which allows the tip to drag and position the atom anywhere on the surface. IBM this technique called 'A Boy and His Atom' (**https://www.youtube.com/watch?v=oSCX78-8-q0**).

Atomic force microscopy (AFM)

The disadvantage of STMs is that the surface must be able to c... ...city, ot complete and no potential difference between the surfac... and ... up. Atomic however, can also image the surface of insul... ...ria...

An AFM uses a technique that ... variations in the movement of a ti surface. The tip in thi... and down purely due to the electrostatic rep the microsco... that ... perceive as touch. To measure such tiny variations

The tip used is a cantilever, a spring-like object that will experience a restoring forc equilibrium position, such as being pushed up or down by the atoms of the surface of this cantilever, and a detector is positioned in the path of this reflected laser bea away from the surface and cantilever so any small variation in the cant[illegible] is ampli



The difficulty with AFM is the number of sources of forces that can act on the canti cantilever could be due to:

- **Van der Waals forces**. These are the forces caused by the electrostatic attract is an object that is positively charged on one side, and negatively charged on t (due to the electric field) and attract one another.
- **Electrostatic forces**. These are caused purely by the attraction [illegible]sion du tip and surface.
- **Chemical forces**. These are caused by the covalent or ionic bonds between a These forces tend to be short range compared to the others.
- **Capillary forces.** A liquid layer [illegible] surface (or condensation in the air) will surface, creating a sort of attraction between the two. The meniscus (the bound result in strong [illegible] dominate all other forces. To get around this, the A [illegible] meniscus can form, or is used in a vacuum.

Comprehension questions

1. Name the pieces of apparatus needed to set up a schlieren photography static
2. Describe how schlieren photography is useful to aerospace engineers.
3. What is meant by quantum tunnelling?
4. Describe capillary forces acting on an AFM and how they can be reduced/remo

Discussion

Discuss the possible applications of STMs and AFMs. Recall that an STM can move surface.

Extension

Research another way to image things with [illegible] electromagnetic radiation and similar style to this article, on this imaging technique. Possible topics to research ar

- electron microscop[illegible]
- medical imaging [illegible] ultrasound

Meta-magic

4.4.2 Electromagnetic waves

Keywords

Material	The type of matter which [illegible] object is made from
Black body	An object that absorbs all [illegible] radiation on it.
Refractive index	The measure of [illegible] light slows down when it propaga[illegible]

What's [illegible] about metamaterials?

[illegible]netic radiation, i.e. light, is made up of an electric field and a [illegible] field, each oscillating with the other. Natural materials generally only affect the electric part of light, causing common optical effects such as refraction. However, it is possible to develop materials that also interact with the magnetic part, leading to new effects unseen in nature. These materials are called metamaterials because they go beyond what is observed in nature (meta – Greek preposition meaning 'beyond').

Every time a news article reports on new findings in metamaterial science, a reference to Harry Potter's invisibility cloak tends to be made. This is because some metamaterials have the ability to bend light around an object witho[illegible] object, effectively making the object invisible. Although current metama[illegible]ls can [illegible] certain wavelengths of light in the infrared or radio wave parts [illegible] spectrum, an[illegible] Realistically, it will be many decades before commercial applications [illegible] can bend [illegible] That doesn't mean metamaterials should be ignored [illegible] research gets to this [illegible] are many revolutionary applications of [illegible] materials.

Radiative [illegible]

[illegible] the Earth and its atmosphere act approximately like a blac[illegible] [illegible]sorbs radiation from space, mainly from the Sun, and emits radiation ba[illegible] [illegible] due to its temperature. For a body at constant temperature, the emissio[illegible] and absorption of radiation is equal. However, the Earth receives a large amount of radiation from the Sun during the day, and then very little during the night. This ca[illegible] the temperature of the atmosphere to vary accordingly, normally lagging behind th[illegible] intensity of radiation by a few hours. This is nothing new, everyone knows it gets h[illegible] during the day and cold at night.

During the night there is very little radiation being absorbed by the atmosphere fro[illegible] space, but there is a lot of infrared radiation being emitted into space. The tempera[illegible] absolute zero at 2.7 K. The temperature of the Earth's atmosphere and surface is ab[illegible] not radiating on the Earth, there is a large temperature gradient from th[illegible]ound o[illegible] 300 K mostly emit radiation with wavelengths in the range 8–1[illegible] [illegible]ch happens [illegible] which Earth's atmosphere barely interacts with. Therefore any radi[illegible] emitted u[illegible] temperature will just escape into space. The [illegible] of [illegible] can, therefore, be u[illegible] Earth's surface!

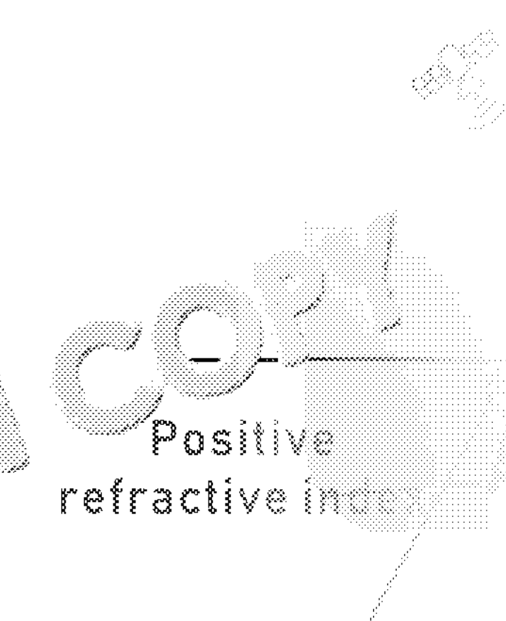
This principle was used [illegible] to make ice in the desert. They would fill sh[illegible] the end of the day [illegible] temperatures in the desert drop rapidly at night, but not b[illegible] [illegible]ld [illegible] (via infrared radiation) that would escape up into the sky a[illegible] [illegible]hall[illegible], the surface area that could radiate heat was larger, improving the [illegible]ature of the water to drop below 0 °C causing it to freeze. The Persians [illegible] be[illegible] sunrise and store the ice in cool ice houses to use later on.

The issue with this cooling technique is it can only be used at night. During the day overwhelms the emitted radiation from objects, causing their temperature to increa come in. Aaswath Raman and Shanhui Fan run a company called Raman Lab. They reflects most light but allows a small window (8–13 µm) of wavelength pass th this material, any incident radiation from the Sun will be reflect ou the infr object due to its temperature can pass through the material and escape into space.

This is very unintuitive because an object material will cool down whe (with no direct line of sight to space) and into the Sun. Theoretically, this m the temperature of an below its surrounding temperature, althoug 5 °C below ambient have been reached.

application of Raman Lab's metamaterial is a filter on cooling panels. The n air-conditioning system. Water flows from the air-conditioning unit a ed on the roof of the building. The water then cools in these panels and flo system. Field trials have shown this increases the efficiency of the cooling system b

Adaptable antennas



A typical antenna will emit a signal in all directions at once. If there is only once receiver, say a satellite in space, then the majority of the energy used to emit the signal misses the satellite and is wasted. A satellite dish is better as it can be directed at the satellite to emit a beam containing the signal; however, this involves the mechanical movement of the dish.

A new type of antenna is a flat p They have no mechanic ste sing a mix of electronics and to control the direction nal. lat antenna developed by o metamaterials to further improve the function of the flat antenna. of individual elements, each able to refract light in a certain direction. Th refractive index (see right). The individual elements can be turned on and electronics in such a way as to track the satellite as it moves across the sky, even th actually moving. These antennas are much more efficient than standard antennas b compared to satellite dishes, making them useful for mobile applications such as pl

Comprehension questions

1. What is the definition of a metamaterial?
2. What wavelength range do objects at 300 K mostly emit electromagnetic radia
3. How did the Persians create ice in the middle of the dessert?
4. What is meant by a negative refractive index?

Discussion

In groups of three or four, try to many applications of Raman Lab's metamaterial as you can. could include transportation, civil enginee

Extension

ow metamaterials that bend light around an object, i.e. make it invisible ths, work and if the Harry Potter cloak of invisibility is a possibility in the n to your class as a two-minute presentation.

Interferometers: Getting into Su

4.4.3 Superposition

Keywords

Superposition	The interference of two waves th eit er ud or subtract from a resultant wave
Relativity	The idea that he p ys system can depend on the relative and
Space-time	f ur-d ensional continuum that comprises of three spatial nsion.

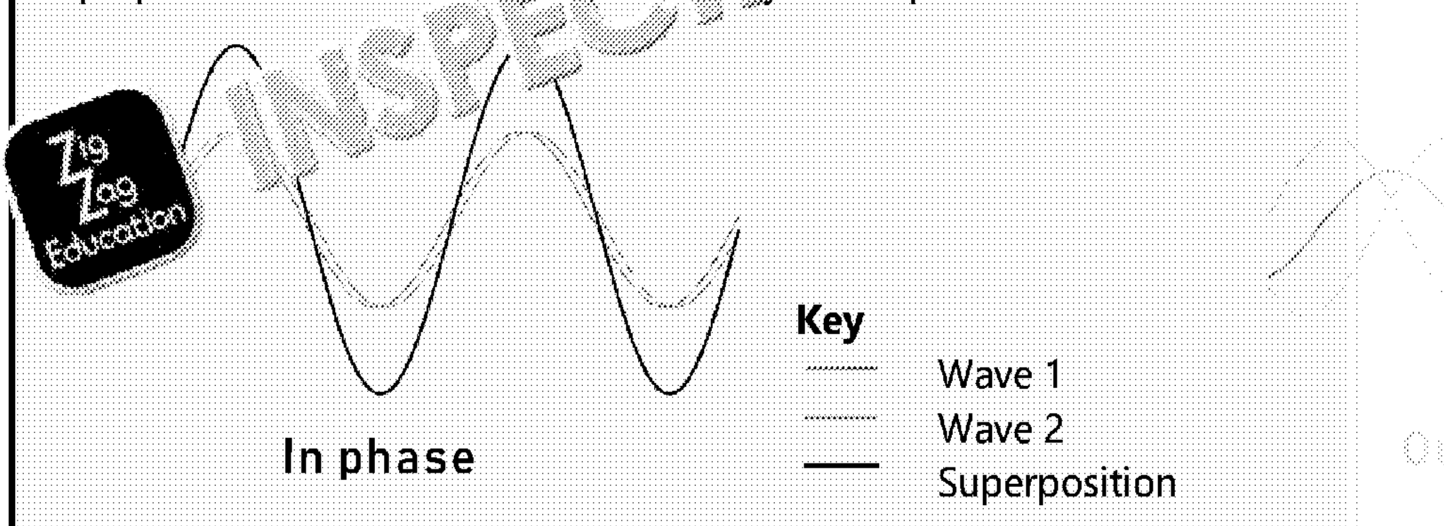
A ometer is a tool that measures the intereference between two waves. Th extremely small changes in distances, useful in many scientific experiments.

Basic principles

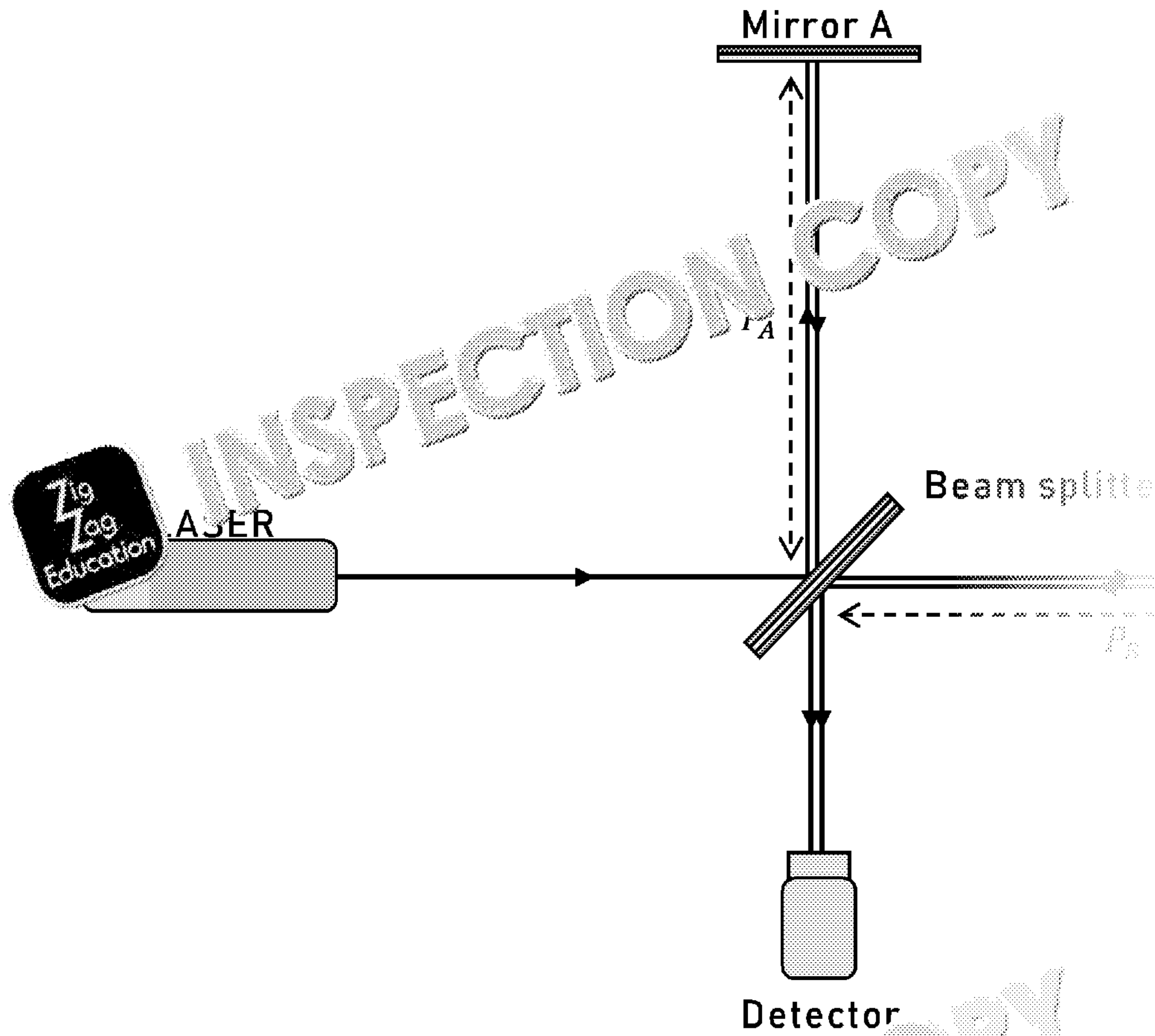
The linear interferometer is the simplest form of interferometer. Devised by Albert device shines light at a beam splitter, creating two beams, A and B, that propagate These beams reflect off mirrors and return to the beam splitter.

The waves of these two beams interefere and propagate towards a detector. The b the same source of light, so are initially coherent (in phase); however, if t path len different they return to the beam splitter and interefere out of p e easure therefore, be smaller due to waves destructively interferin .

The superposition of two waves th arl phase produces a wave with mu superposition of two wave are r y out of phase.



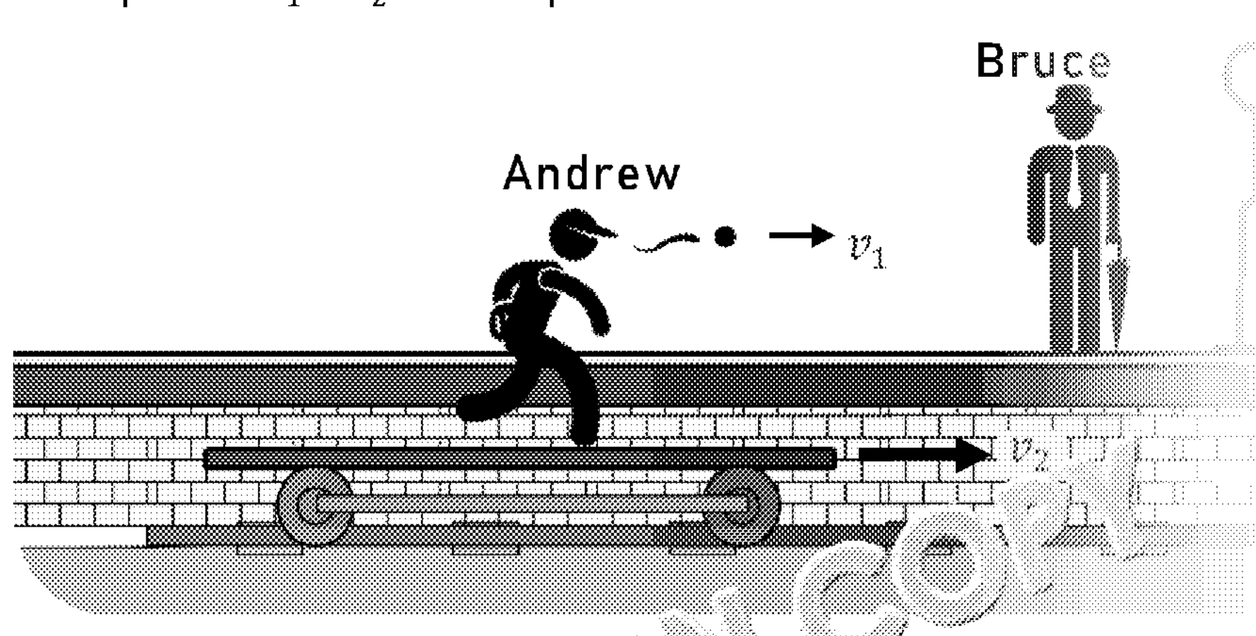
The phase difference between the waves is related to the difference in path length c using extremely coherent light, such as LASER light, with small wavelengths, small v can be measured.



The first and most famous application of the interferometer was performed by Albe in 1887. At the time it was thought that the laws of physics obeyed Galilean relati to how velocities of objects are perceived by different observers.

Galilean Relativity

Consider a baseball pitcher, Andrew, travelling on a train at a speed of v_2 m s d of v_1 m s^{-1} in the direction of travel of the train. An observer on the pl travel at a speed of $v_1 + v_2$. This simple addition of velocities for different obs



During the nineteenth century, physicists thought that just like the way sound wave must propagate through a medium called the 'aether'. Also during the mid ninete calculated that light should travel at a constant speed.

Galilean relativity tells us that if Andrew shone light in the direction of motion of the ght as its intial speed plus the speed of the train. Therefore, the speed of B different. It was thought that this constant speed calculated by Maxwell wa its aether, a constant in the background. Up until this point, however, the aether h observed. No other matter interacts with this aether, it's only suggested to explain

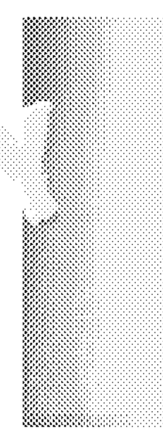
This is where the Michelson–Morley experiment comes in. Their hypothesis was th
this aether, the two arms of the interferometer will be travelling at different speeds
results in a difference in path length which will result in some change in interferenc
experiment found no change in the path length between the two arms.

Light propagated along each arm at the same speed; therefore it was not constant
just constant to any observer. This contradicts Galilean relativity and eventually lea
relativity, making this one of the most influential experiments in science.

Detecting gravitational waves

Einstein revolutionised how we thought about time and space with his theory
his theory of general relativity. While the special theory of relativity appl
systems at constant speeds, general relativity applies to accelerating objects.

One aspect of general relativity is its application to gravitational fields. Imagine you
weighing scale. Standing on the weighing scale when the elevator is stationary give
elevator starts accelerating upwards at $g = 9.81$ m s^{-1}, the weight would instead rea
space and accelerating upwards at 9.81 m s^{-1}, the weighing scales would still read W
inertial effects (acceleration) and gravitational effects are indistinguishable, and can



General relativity explains gravity as a curvature in space and time, which light follows. This means that gravitational effects can only travel at the speed of light and no faster.

This weird consequence means that if the Sun were to suddenly disappear, the Earth would continue to orbit about the point where the Sun was for another 8 minutes (the time it takes light from the Sun to reach Earth). The theory implies that the speed of light is not unique to light, but is the speed limit of how fast information can travel through the universe.

Special relativity and general relativity describe space and time to be one four
. Objects with mass distort this space-time, causing it to 'bend' towards
c as gravitational forces between objects with mass.

If an object with a large enough mass distorts space-time with a large enough pow
like water waves rippling across the surface. The energy needed to create these rip
is enormous, even on the cosmological scale. Therefore, only events like the mergi
holes will result in gravitational waves, and even these waves are small.

Detecting these waves requires extremely precise equipment, such as an interferom
emitted from somewhere in outer space will pass through the Earth, causing the spa
to oscillate. The length of the arms of an interferometer will, therefore, vary and th

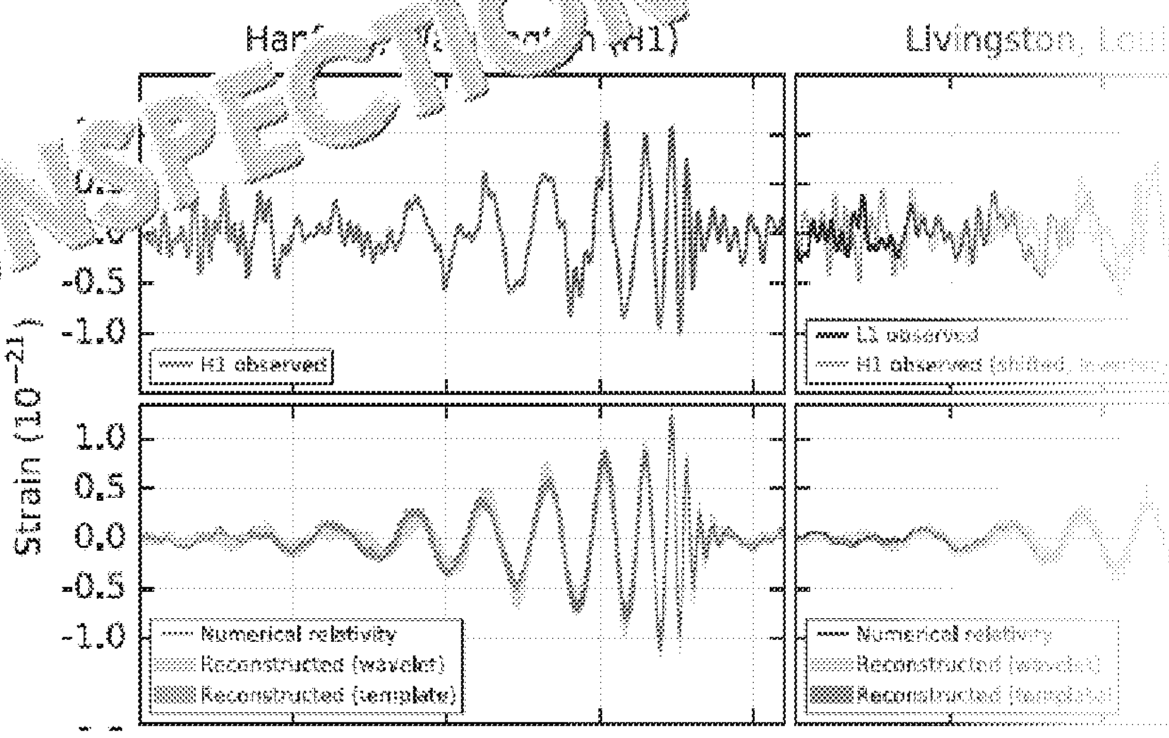
The Laser Interferometer Gravitational Wave Observatory (LIGO) is designed to do e
consists of two interferometers situated 3000 km apart in the US. By using two inte
source of the gravitational waves can be deduced.

Each interferometer has arms that are 4 km long, 360 times longer than the interferometer used by Michelson and Morley! At the end of each arm are 40 kg mirrors suspended at the end of a four-segment pendulum (a pendulum hanging fr a pendulum hanging from a pendulum that is hanging from a pendulum). This
any vibrations from the ground, reducing noise in meaurements. There ar
tricks to reduce noise, such as passive and active seismic isolation
mechanisms.

To further increase the sensitivity of the interferometers, mirrors are added near the
travels up and down its arm many times before interfering at the beam splitter. Thi

the LIGO interferometers 1120 km long, 144,000 times longer than the interferomet Morley! All of this means the LIGO interferometers can detect a change in arm leng

After only a few days of operation, on 14th September 2015, both LIGO detection sit gravitational wave. It was created by the merging of two 30 M black holes mass 1.3 billion light years away (this means this event happened 1.3 billion years ago, ar after turning the interferometers on!). Below is the signal detected by each LIGO de



Since then, four other black hole mergers have been detected and the first neutron 17th August 2017. LIGO is currently on pause but will continue operation in late 201

The European Space Agency hopes to build its own gravitational wave detector – the Laser Interferometer Space Antenna (LISA) will work on the same principles as LIGO but will have arms 2.5 milli contend with interference caused by vibrations and other sources, making LISA a smaller and lower-frequency gravitational wave

Comprehension questions

1. ... in how the interference between two beams allows an interferometer to ... es in distance.
2. What was the aim of the Michelson–Morley experiment?
3. What was proposed by Einstein to solve the issue of the results of the Michelso
4. How large were the black holes that merged to create the first detected gravit

Discussion

Previously, astronomy has collected all of its data by looking into the sky and detec electromagnetic radiation emitted by the stars and galaxies. Now with the advent of there is a new way to study the universe. Discuss as a group the implications of this universe.

Extension

The Laser Interferometer Space Antenna, or LISA ... on, proposed set of satel position themselves to form a huge i... me... It will differ from a standard line three spacecraft, arranged in a triangle with sides that are 2.5 million km long. Desig be used in a science ... on.

Holograms: Seeing Things That a

4.4.3 Superposition

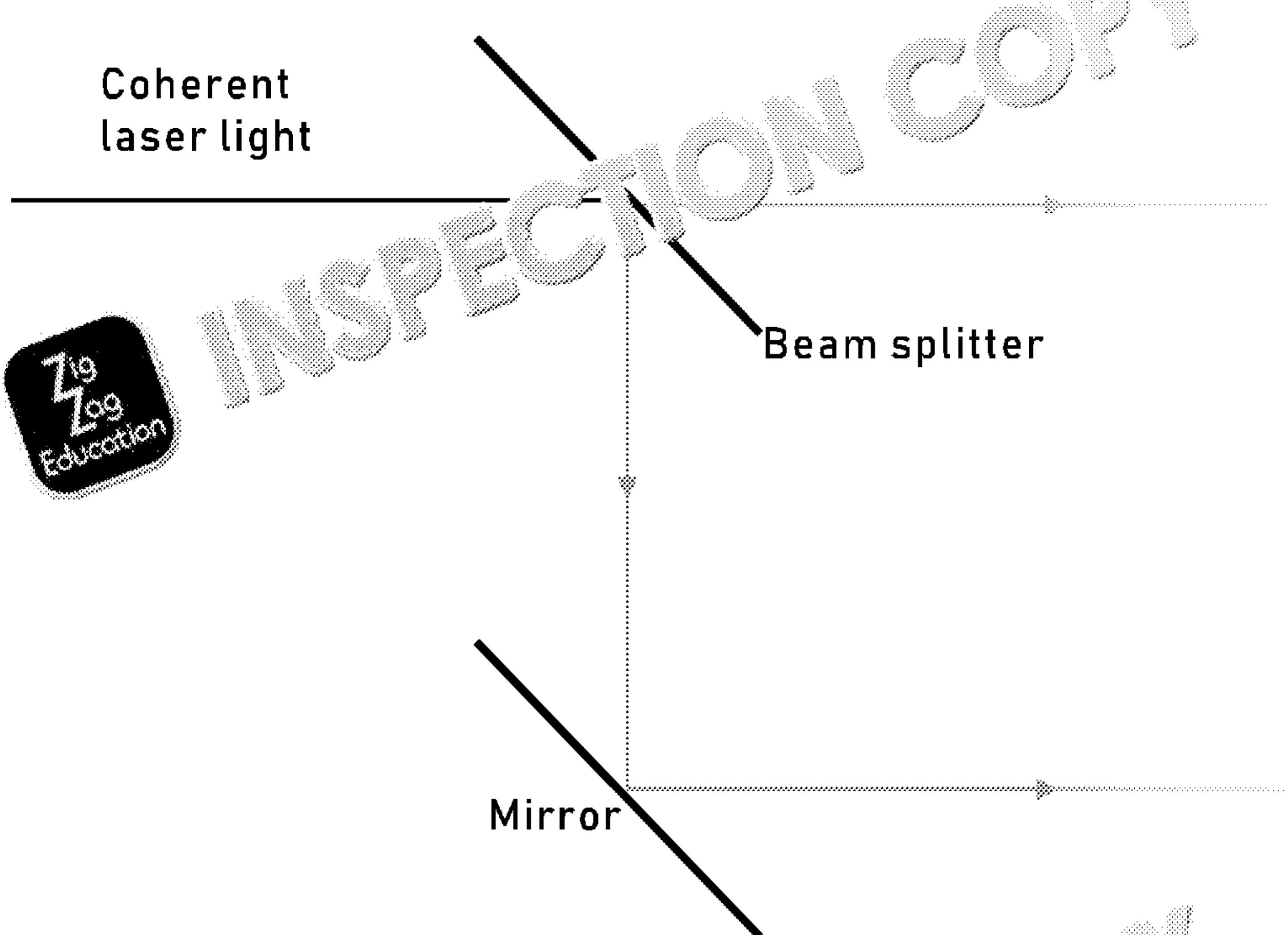
Keywords	
Laser	A device that emits coherent light at a ... frequency
Lens	A transparent object that ... light in a way to converge or d
Interference	The superposition ... waves when they propagate through t

In Greek, holo means whole and -gram means 'message', so a hologram is a whol... ...d in ... 'hologram' has been used to mean a message or image created ... appears to float in space as if a real object was there. This illusion can be ... the most common uses coherent laser light with holographic plates.

Laser holography

A laser beam is split into two using a beam splitter. One of these beams is directed reflected off the object towards a holographic plate. The second beam skips the ob the holographic plate using a mirror. This second beam is known as the reference b

The two beams meet and interfere at the holographic plate. Their interference patt holographic plate, just like the way a camera takes a picture by exposing a photogr



The pattern recorded on the holographic plate doesn't look like the object to the na information to display a 3D image of the object is encoded in this pattern. To displ holographic plate must be illuminated with a beam identical to that used to recor reconstruction beam either transmits through or reflects off of the holographic plat an observer.

The emerging wave front from the holographic plate is exactly the same as if the object was actually there. Therefore, optical manipulation such as placing a lens in the path of the wave front will magnify the image of the object, just as if the observer was looking at the real object through the lens.

A common example of reflecting [illegible] be found on credit cards [illegible] these holograms are [illegible] to produce, making fraudulent [illegible] more [illegible], strengthening the security [illegible]

Dynamic holograms

The classic laser holography process is equivalent to taking photos and printing them out. But what is the holographic equivalent of videos and are they even possible?

Well, the technology is young but with the use of metamaterials, generating holograms that can change with time are possible. A metamaterial is a material that 'goes beyond' what is naturally possible. Basically, these are materials that are designed and engineered to manipulate light in a specific way.

In early 2017, a team of scientists published a paper on a metamaterial they had developed. Their [illegible] would turn nano-sized silicon discs on and off [illegible] the direction of polarised light passing [illegible] the [illegible] so the later interference produ[illegible] image. The sites are [illegible] so can switch on and off in quick enough succession to pr[illegible] a [illegible]amic hologram.

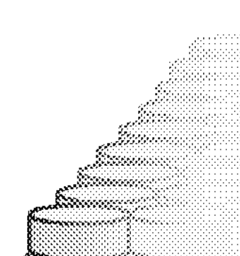
T[illegible] Wars-esque dynamic holograms won't be replacing our video calling a[illegible] the primary method of communciation.

Acoustic holography

Holograms aren't specific to light. Any wave can be used to create a hologram, incl[illegible] process works slightly differently to laser holography. The basic principle is to prod[illegible] that interfere to create a pattern of pressure variations in the medium in which they[illegible]

One method uses a 3D printed sheet placed on top of a speaker. This sheet is designed in such a way as to transmit the sound to create the desired pressure waves. Another method uses an array of speakers that emit waves that interfere with one another, creating pockets of high and low pressure.

This second method has the [illegible]cation of levitating small objects. The object gets stuck [illegible] well, with high pressure air surrounding [illegible] due to these high pressure areas is strong [illegible] the weight of the object, and any small [illegible]ns by the object, keeping the object in place. This a[illegible]n could be useful in manufacturing or in medicine where there is a need to transport an object without making direct contact with the object.



The holographic principle

The three-dimensional image produced by a holographic plate looks exactly like the in theory, whereas in reality things like resolution and dirty mirrors/lenses interfere of the information that generates this three-dimensional virtual image is stored on plate. This storing of information of an n-dimensional object on an $(n-1)$-dimensi **holographic principle**.

The holographic principle comes from **string theory**. In string theory, all particles dimensional strings or loops, though these strings are one-dimensional, they multidimensional worlds we see in the world around us. In fact, in string theory, the dimensional (3 spatial dimensions + time) representation of an 11-dimensio

The holographic principle also applies to black holes, and can explain the black hol

A black hole is the remnant of a very massive star. It's so dense that not even light surface around a black hole called the event horizon, where anything that crosses it no chance of escaping. As the object falls into the black hole it takes its information molecules and how they are arranged to make up the object.

A problem arises when merging this extreme case of gravity with quantum mechani mechanics state that information cannot be created or destroyed, just moved arou into a black hole isn't destroyed, where does it go? According to the holographic p information contained by the matter is displayed as deformations in the 2D surface horizon.

Some scientists have taken this principle one step further and suggested the inform stored on a two-dimensional surface, just as on the surface of a black hole. This im hologram, projected from this hypothetical two-dimensional surface. If this is true noise due to this hologram should be detectable by gravitational wave detectors, su but as yet there is no evidence for the theory.

Comprehension questions

1. What is meant by the reference beam?
2. Describe the construction of a metamaterial that can produce dynamic hologra
3. Describe one application of acoustic holography.
4. How does the holographic principle propose a solution to a problem found wi quantum mechanics?

Discussion

Discuss the possible implications of the holographic principle if it applies to our enti does this theory affect your view of the universe?

Extension

Holograms are commonly used on credit cards and bank notes as a form of security other common application of holograms and present your findings as a short repor

Gateway to the Quantum

4.5 Quantum physics

Keywords	
Black body	A body or object that absorbs all incident radiation
Photons	Quantised packets of electromagnetic radiation
Wave function	The description of a quantum mechanical state of a particle

Classical or Newtonian physics describes the physics developed before the twentieth century. It is based on Newton's three laws, his law of gravitation, the laws of thermodynamics and Maxwell's equations on electromagnetism among others. Classical physics assumes that energy is continuous (it is possible for a system to have any value of energy), that time progresses at a constant rate, and that the length and mass of an object are the same for different observers, among other intuitive assumptions. Classical physics explained the world pretty well; however, there were a few discrepancies that needed to be resolved before a unified theory was formulated.

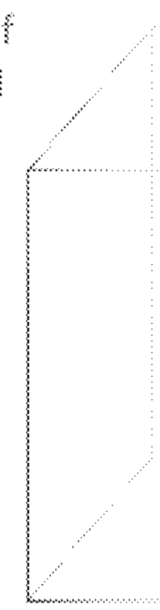
The quantisation of light (1900)

From studying black bodies, you know that all objects emit radiation, with the wavelength of the radiation depending on the object's temperature. Humans have a body temperature that causes us to emit infrared radiation. The hotter an object is, the shorter the wavelength of emitted radiation.

This was all well known in classical physics and is described by the Rayleigh–Jeans law, which worked at long wavelengths, but broke down at short wavelengths (high energy/temperatures). Wien's law was able to describe the emitted radiation for short wavelengths, but deviated from experimental data at long wavelengths. Therefore, there was a need for the two models to be combined into one.

Max Planck proposed a theory that could explain the experimentally observed radiation at high and low temperatures in 1900. The beginning of the derivation of the Planck law is as follows:

Consider a volume in a black body in the shape of a cube with sides L. If the black body is at the same temperature, T, then the inside and outside of the volume in question are in thermal equilibrium.



The electromagnetic radiation can take lots of different wavelengths, but must be a whole number of wavelengths, so can only take certain modes, shown by the diagram to the right. Think of it like stationary waves of a string – the wave can have an infinite number of wavelengths, but only certain wavelengths won't interfere destructively, so only certain wavelengths are seen.

In one dimension, x, the possible wavelengths of the modes are:

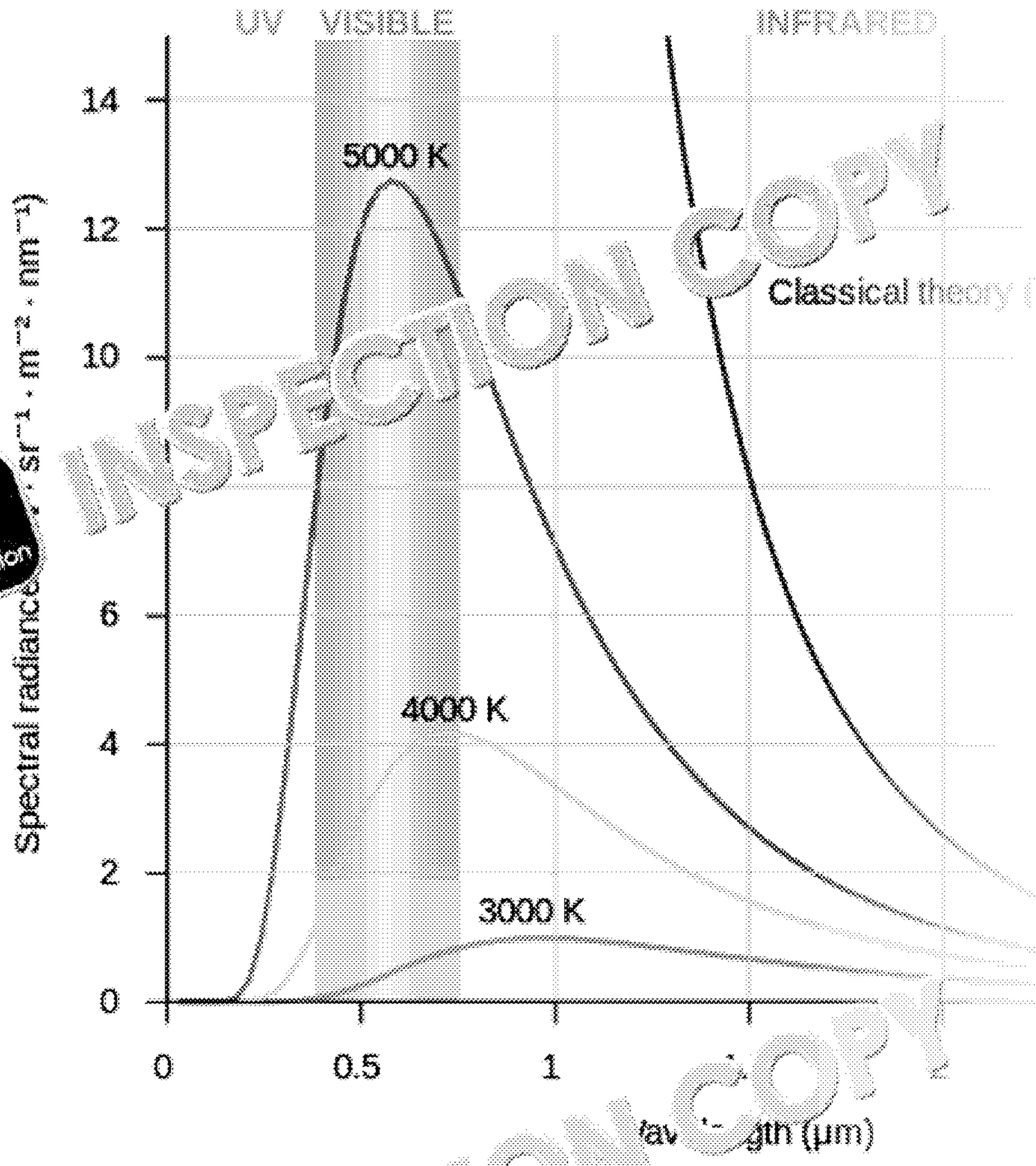
$$\lambda_x = \frac{2L}{n_x}$$

where n_x is an integer. A simple periodic function is the sine function, so the modes that describe the EM radiation in this cube are of the form:

$$\sin\left(\frac{\pi n_x}{L}x\right)$$

Following the derivation through leads to Planck's law of radiation:

$$B(\lambda, T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda k_B T}}-1}$$



The graph above sh... for different temperatures, as well as the Rayle theory plotted ... 00 K. The peak for temperatures of around 5000 K is in th ... e s... light.

...ting thing about the derivation of Planck's law was the modes that are se represent the energies of electromagnetic radiation possible and only a discrete (al of these modes are allowed. This contradicts the assumption of classical physics tha quantity.

Planck initially thought the quantisation of electromagnetic radiation to formulate h workaround and didn't mean anything physically significant. A couple of years late a model for the photoelectric effect. The physics at the time expected the energy o photoelectric effect to increase with the intensity of the incident light. However, exp frequency of light that determined the energy of the electrons. Einstein suggested packets called photons, and one photon collides with one electron only, suggesting particle.

The energy of a single photon can be extracted from Planck's law:

$$E = \frac{hc}{\lambda} = hf$$

The quantisation of matter (1913)

Niels Bohr also suggested that the energy of atoms is quantised. Specifically, that electrons can only exist around the atom in discrete orbits, dependent on their energy.

Think of the circumference of each electron orbit. Similar to the standing waves in Planck's derivation, each electron orbital is a standing wave that 'holds' the energy of the orbital. Only certain standing waves are allowed, so the energy of the orbital is quantised.

The similarity between the quantisation of light and matter is further realised in wave-particle duality. Hypothesised by Louis de Broglie, waves, such as light, can act like particles (photon) and particles, such as electrons, can act like waves (so diffract, refract, e… backed up with evidence from experiments, despite being unintuitive.

The Schrödinger equation (1925)

The shape of an electron orbital is modelled by a **wave function** – this gives the pr… a specific place. Erwin Schrödinger developed an equation that modelled how a wa…

The Schrödinger equation is fundamental to quantum physics. It is best to describe a particle trapped in an infinite potential well.

Did you know?

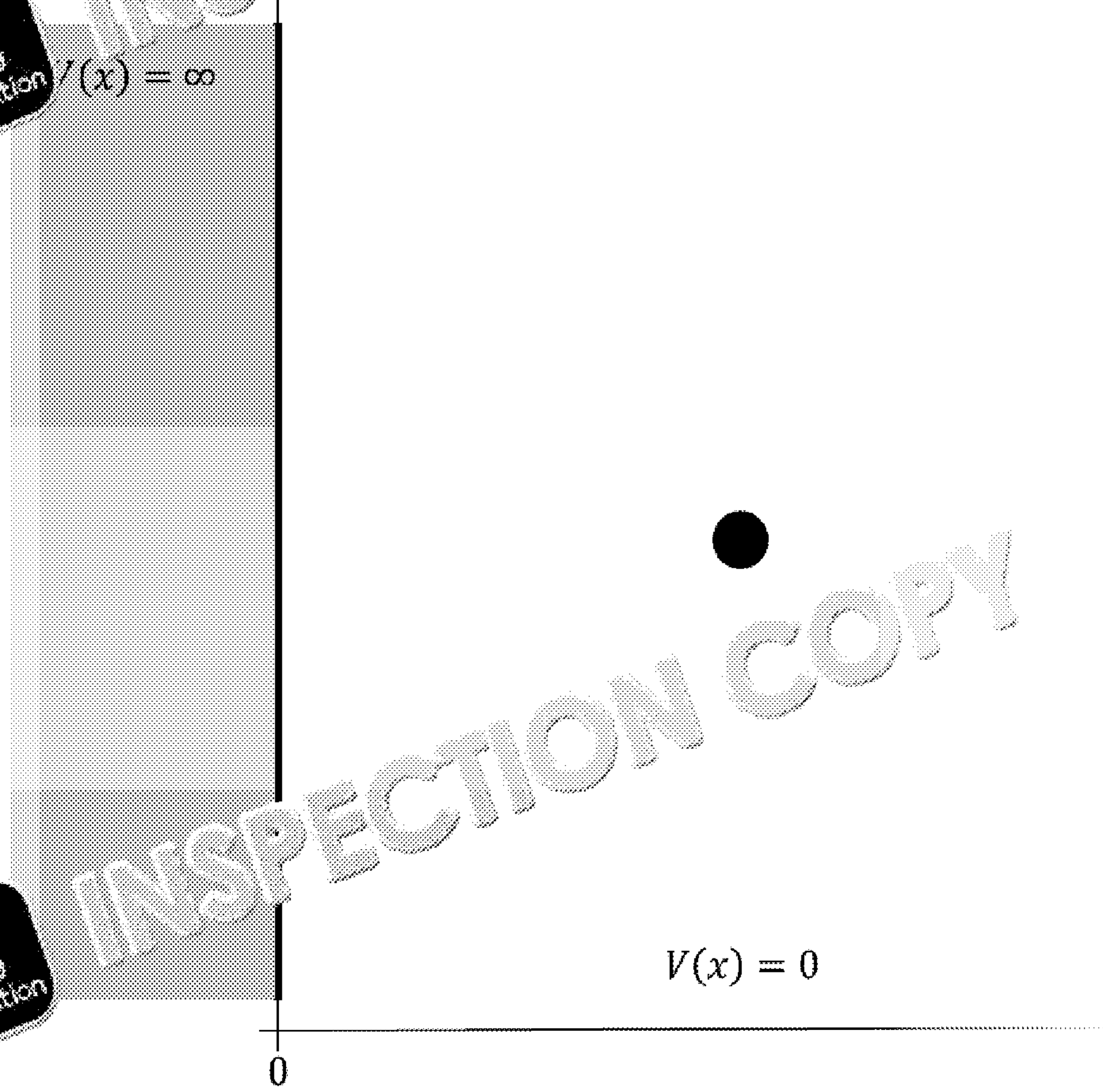
Max Planck was awarded the Nobel Prize in **1918** for his derivation that lead to the discovery of photons, **Albert Einstein** was awarded the Nobel Prize in **1921** for his work on the photoelectric effect, **Niels Bohr** was awarded the Nobel Prize in **1922** for his work on quantised orbitals in atoms, and **Louis de Broglie** was awarded the Nobel prize in **1929** for his work on the wave nature of electrons. A successful 11 years for quantum theory!

Particle trapped in an infinite potential well

For simplicity, we will ignore the progression of time and only consider motion in o

A particle is trapped in an infinite well, that is, it's trapped between tw... walls of infir... escape. Outside the well, there is a barrier of potential energy of V(x) = ∞, and insid... of V(x) = 0.

The position of the particle can be ... the time-independent Schrödinger



$$-\frac{\hbar}{2m}\frac{\partial^2}{\partial x^2}\psi(x) = E\psi(x)$$

To describe the particle in this well, this equation needs to be solved for $\psi(x)$, calle... function of a particle is a description of the particle in space and time, giving the pr... in a particular location at a particular point in time.

Solving the Schrödinger equation for our particle in an infinite well gives the solutio

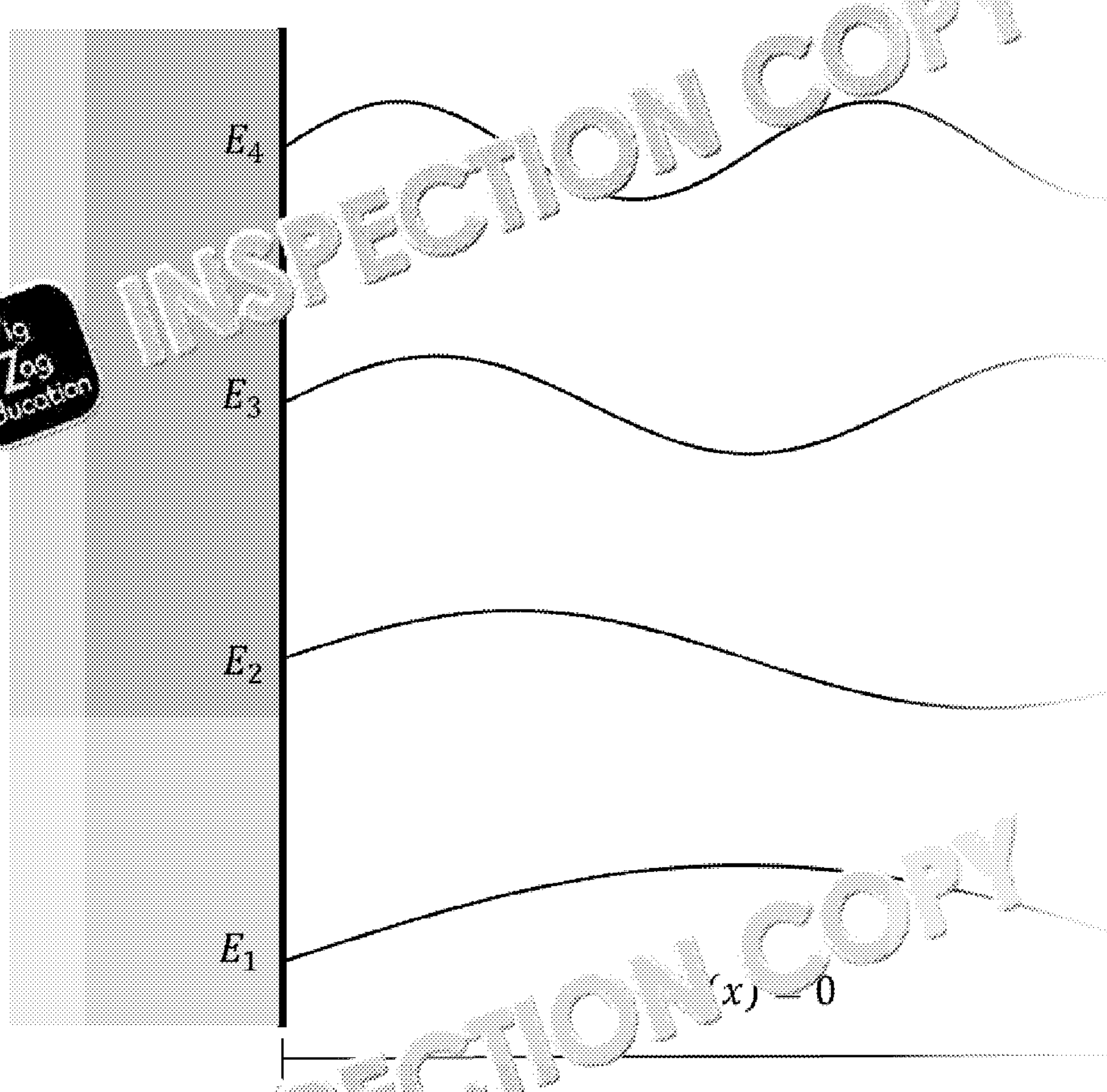
$$\psi_n(x) = \sqrt{\frac{2}{L}}\sin\left(\frac{n\pi x}{L}\right)$$

where n is an integer (representing ... discrete possible solutions). You n... solution of the electromagnetic radiation modes in the derivation of Planck's law. T... states crop up often in quantum mechanics. It's also possible to derive the energy a... fu...

$$E_n = \frac{n^2\pi^2\hbar^2}{2mL^2}$$

As the mode of the wave function increases, so does the energy of the particle.

Each wave function corresponds to a possible state the particle can be in. Each st
the particle, given by the energy equation above. The particle cannot exist within th
have one of the quantised energies from this equation. Below is a plot of the first
in an infinite potential well.



F... sta... ...bility of finding the particle at a point x is given by the squ

Example

For an electron in its ground state (the lowest possible state, $n = 1$), in a potenti
what is the probability of finding the electron in the centre 2 pm of the well?

$$p(4 < x < 6) = \int_4^6 p(x)\,dx = \frac{2}{10}\int_4^6 \sin^2\left(\frac{\pi x}{10}\right) dx$$

$$p(4 < x < 6) = \frac{2}{10}\left(1 + \frac{5}{2\pi}\left(\sin\left(\frac{4\pi}{5}\right) - \sin\left(\frac{6\pi}{5}\right)\right)\right)$$

$$p(4 < x < 6) = 39\ \%$$

So there is a 39 % chance of finding the ... between x = 4 and x = 6, i.e. in t
how this probability doesn't d... o... mass of the electron, only its energy
dimensions. The en... el...tron in this ground state is:

$$E_1 = \frac{\pi^2 \hbar^2}{2(9.11 \times 10^{-31})(1 \times 10^{-11})^2}$$

$$E_1 = 6.02 \times 10^{-16}\ \text{J}$$

$$E_1 = 3.8\ \text{keV}$$

The orbital of an electron in an atom is a type of potential well. This potential well l functions, and, therefore, energy levels that can exist. This is why Niels Bohr sugges have discrete energies, which led to his Nobel Prize.

The predictions from the Schrödinger equation and other quantum mechanical theo experiments. Today, quantum mechanics and its related theories are considered some theories ever developed.

But what do these equations mean? What is the physical significance of the wave f Bohr, Heisenberg and others tried to answer these questions. Their description is k interpretation.

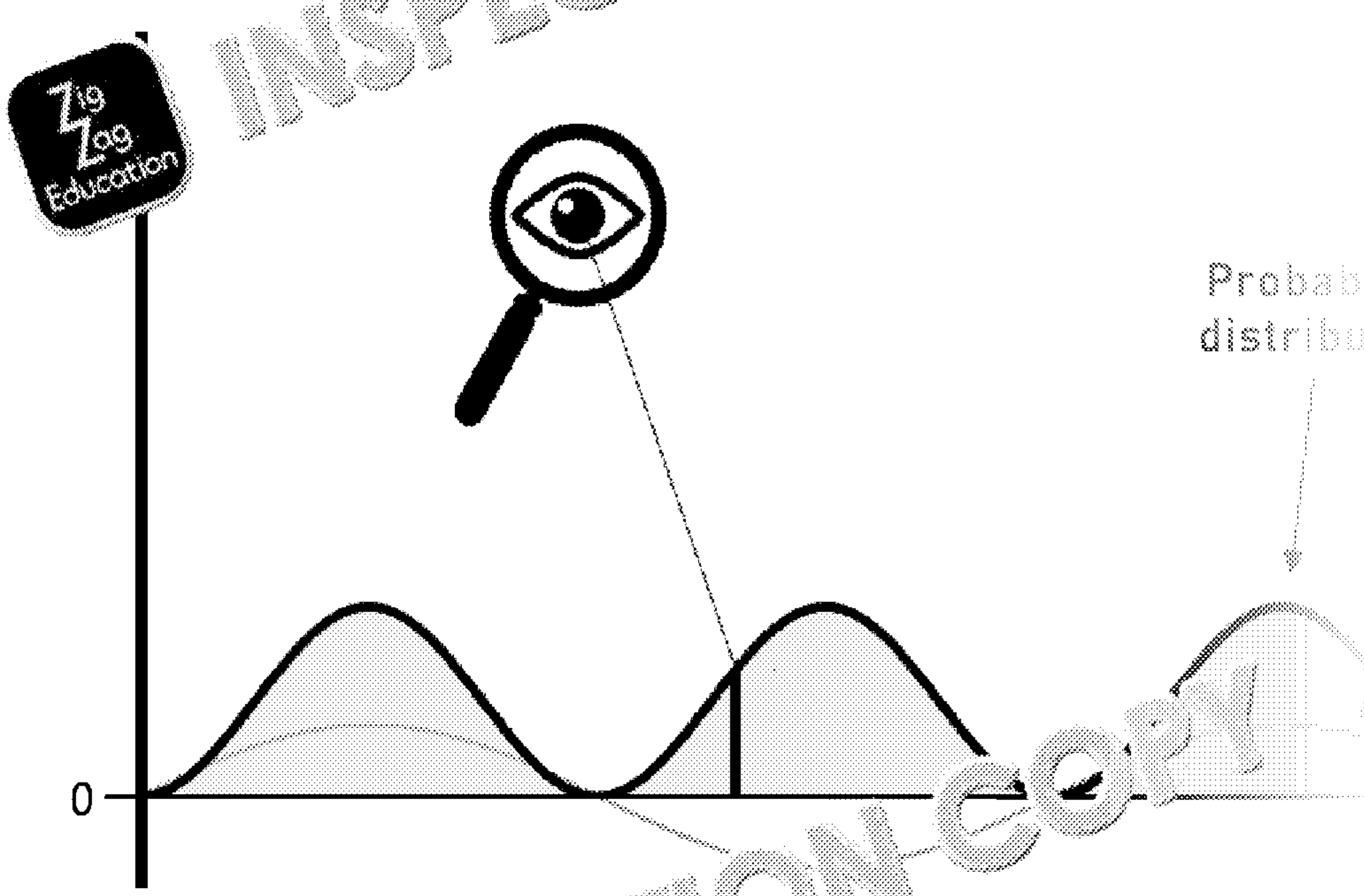
The Copenhagen interpretation

Devised between 1925 and 1927, the Copenhagen interpretation came from a meeting of world-leading physicists to try and determine the physical meaning of the theories and results emerging from quantum mechanics.

Normally prob one number, li coin flip. A prob graph that repr system can tak the case of ou the x-axis).

The interpretation states that a system is in all possible states at once. So our particle in the infinite well is at all positions along the x-axis at the same time! Just let that sink in for a second. The particle only 'decides' to be in a particular position when forced to by being observed, or interacting with its environment.

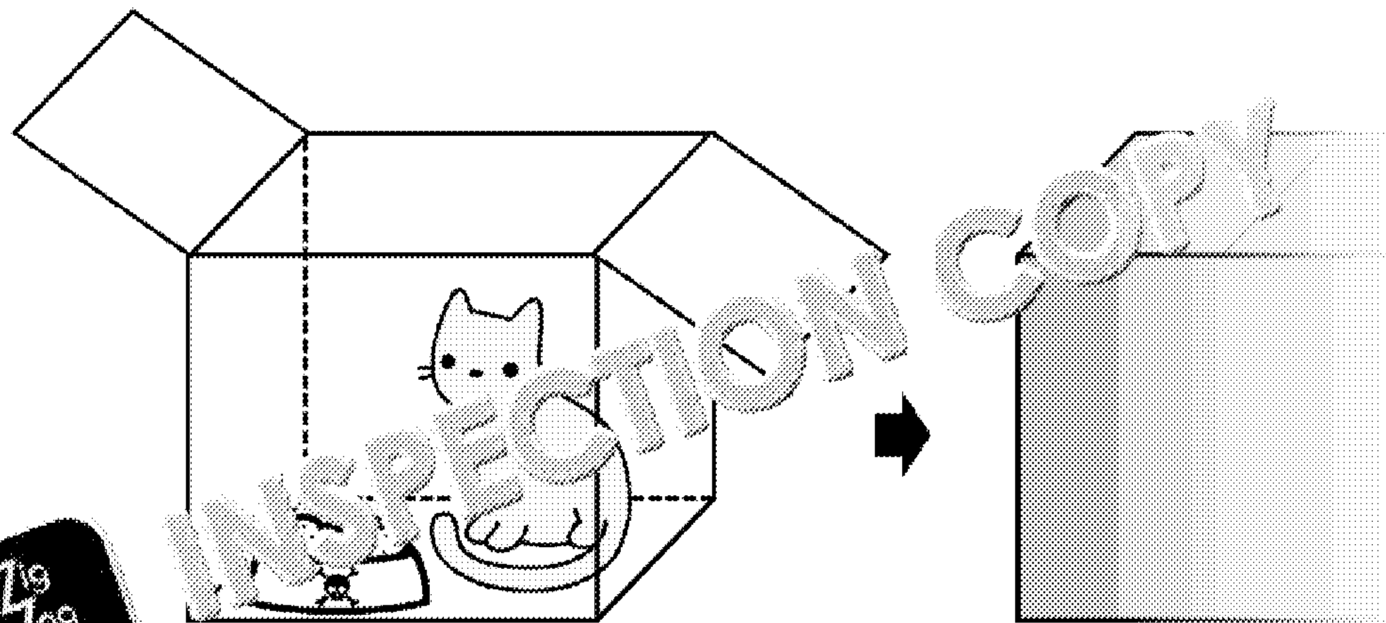
Each state has an associated probability calculated from the wave function. Below is function, $\psi_3(x)$ and its associated probability distribution for our particle in an infin has this wave function when its energy is . When the system is influenced by an measurement, the system collapses into one state, depending on the associated pro



So the wave function for our particle collapses into one position, i.e. we measure th the centre. Repeating this measurement would find the particle in another position are repeated many times, the probability distribution will start to appear. Measurin finding the particle mostly in the grey areas and barely in between them.

The interesting thing about this interpretation is that a quantum mechanical s states at the same time. It's only when an observation of the system is made that th collapses, resulting in the system being in one state; the one that matches the meas

Schrödinger described this principle with a famous analogy called Schrödinger's cat.



A cat is placed into a box with a vial of poison connected to a radioactive nucleus. T
sealed. At any point, the nucleus could decay, breaking the vial, releasing the poison
be known whether the nucleus has decayed or not until it is observed. Thus, it is in a
two possibilities.

While the box is closed, and the nucleus is both decayed and undecayed (quantum
simultaneously considered to be alive and dead, with the probability of the cat's fat
wave function. It is only when the box is opened that the state of the cat is determin
function collapses into a single possibility.

Schrodinger suggested this analogy to point out the flaw in the Copenhagen interpr

Why couldn't the cat be considered an observer? If humans are observers, so could
Does an observer have to be alive? Or could a single atom that interacts with a syst

And then, once we open our box and find a (hopefully) living cat, what has happened
the possibility of a dead cat? Or is there a parallel universe where the
more gruesome s... ... every collapsing wave function of every atom, ele
... a different result?

Comprehension questions

1. Describe how the possible modes of electromagnetic radiation in a confined sp
   quantisation of energy.
2. What does the Copenhagen interpretation say about the quantum states of a s
3. Describe how the famous analogy known as Schrödinger's cat applies to quant

Discussion

How does the Copenhagen interpretation affect larger, classical systems? Is there a
systems quantum mechanics applies to? Does the fact that we don't ... quant
suggest that quantum mechanics is wrong, or that there's ... more complic

Extension

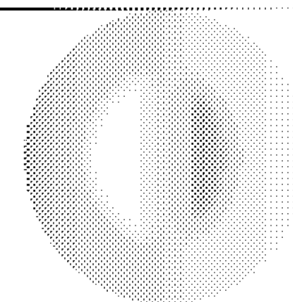
Quantum tunnelling is a ... phenomenon where a particle can 'tunnel' through a
because its wave function ... over the barrier. Research this phenomenon and h
fu... Write ... as an A4 poster to be used in a science fair.

Mark Scheme

Article	Question	Answer
It's Not Exactly Rocket Science	1	$T = (v + v_e)\left(\frac{dm}{dt}\right)$ [illegible] $T = (0 + 1200)(75$ [illegible] $T = 9 \times 10^{[illegible]}$ N
	2	Ar[illegible]om: • $AC + BC = constant$ where A and B are th[illegible] ellipse • The distance between the centre of the elli[illegible] to $e \times a$, where e is the eccentricity of the [illegible]
	3	Periapsis and apoapsis respectively
	4	$v = \sqrt{GM\left(\frac{2}{r} - \frac{1}{a}\right)}$ $v = \sqrt{G(1.99 \times 10^{30})\left(\frac{2}{(2.06 \times 10^{11}}$ [illegible] $v = 2.66 \times 10^{[illegible]}$ [illegible]
	Discussion	Points that could be discussed: • More efficient rockets (drive by basic busin[illegible] space cheaper. • A quicker turnaround of roc[illegible] kes mo[illegible] becomes much m[illegible] gu[illegible] eading to m[illegible] • Competitio[illegible] in t[illegible]e sp[illegible]dustry drives n[illegible] de[illegible] • [illegible]ements in space or on a mission [illegible] [illegible] importance that space or the mission to [illegible] • Expanding the space industry to many priv[illegible] universal standards being lost, although th[illegible]
[illegible]ffe[illegible]	1	Galilean relativity (all non-accelerating referenc[illegible] Maxwell's equations (giving a fixed value for c) time slows down and speeds up depending on [illegible] always travels at c through a vacuum.
	2	$t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}}$ $t = t'\sqrt{1 - \frac{v^2}{c^2}} = 880 \times 10^{-9} \times \sqrt{1 - }$ [illegible] $t = 536$ ns
	3	For the observer, the time it takes for the muon [illegible] because of time dilation, and for the muon only [illegible] For the muon, the Earth is travell[illegible] relativist[illegible] covers through the atmosp[illegible] ont[illegible]cted, s[illegible] whole atmosphere i[illegible]ts lif[illegible]im[illegible]
	Discussion	Points th[illegible] be [illegible]ssed: • [illegible]icle [illegible]erators • m[illegible] imaging • mass spectrometry • GPS • high-precision equipment where even a sm[illegible] timing can have a big effect

Article	Question	Answer
Big Engineering: The International Space Station	**1**	6. Salyut 2 failed during its launch.
	2	It was an international media event because the debris falling on populated areas
	3	The US orbital section (USOS), and the Russian o
	4	Any two from: • Bones become less dense. • Astronauts grow a few inches taller. • Muscles start to waste away. • Red blood cell production decreases. • Immune systems weaken.
	Discussion	Points that could be discussed: • Human travel in space allows us to inhabit • The longer we can get humans to survive in send humans. • It gives us access to planets/asteroids with such as metals that are rare here on Earth. • By sending humans into space we reduce the extinct (due to global disasters, etc.). • Research could help understand and devel potentially saving lives here on Earth. • The increase in funding for the research cre expands the space industry.
Fluid Dynamics: Going with the Flow	**1**	The continuity equation, three Navier–Stokes e equation.
	2	$Re = \frac{\rho v_0 l_0}{\eta}$
	3	$F_D = \frac{1}{2}\rho v^2 A C_D$ $F_D = \frac{1}{2} \times (2.46 \times 10^{-2}) \times 1800$ $F_D = 5.7 \times 10^{4}$ N
	4	The foil splits the incoming air into two parts: o the foil, the other travels underneath. These pa of the foil at the same time. The top of the foil i so the air travelling over the top must travel fas at the same time as the air travelling under the that the faster a fluid travels, the lower the pres pressure on the top of the foil and high pressur upward force called upthrust.
	Discussion	Points that could be discussed: • An exact solution isn't needed to gain impo system. • Techniques developed for one chaotic syst chaotic systems. • An exact solution may be possible, it just ha • The information from studying chao ...s/industries. • The computational power needed to resea purpose/application for powerful compute supercomputers and future technologies.

Article	Question	Answer
Energy Storage	**1**	Thermal energy storage in media such as water
	2	$I = mr^2$ $I = ... \times 0.25^2$ $I = 0.8... \text{ kg m}^2$ $E = \frac{1}{2}I\omega^2$ $E = \frac{1}{2} \times 0.844 \times 2...$ $E = 3.4 \times 10^{...} \text{ J}$
	3	The flywheel stores and releases the generated spreading the power out during each cycle. Th output of the engine smoother and easier to tr
	4	DRAM uses a refresher circuit to keep the store whereas SRAM uses supercapacitors which can longer, removing the need for a refresher circu
	Discussion	Points that could be discussed: • The company could use a miniature pump • They could use large flywheels. • They could use batteries, such as that used • They could use hydrogen fuel cells. • Industrial-sized batteries make most sense types of storage can be sufficiently argued
Earthquakes: Shaking Things Up	**1**	e.g. the San Andreas fault line
	2	$10^{2} ...$ $... 5.6 \times 10^{2...} \text{ J}$
	3	The amplitude of the seismic waves as they are ... their energy) as they propagate through a the amplitude of a seismic wave, the further it ... site.
	4	The use of satellites that are sensitive to the EL spectrum will result in the detection of earthqu This will allow the affected area to properly pre millions of lives.
	Discussion	Points that could be discussed: • Research into geoseismology can increase earthquakes occur, potentially saving a lot • Geoseismology can help develop better ea such as the way buildings are designed and • Researching helioseismology could help de systems against solar flares. These solar fla satellites, including the satellites that predi • Studying helioseismology could help us un reactors here on earth, solvi... energy
Laser Focus	**1**	A gain medium has m... excit... atom... then a photon with the right energy will cause an elec to its g... emitting another photon; t ... These photons will cause more photo stimulated emission, resulting in a chain reactio gain medium ensure generated photons pass b The result is the amplification of light in the ga
	2	5:1
	3	Either oxygen is used to help burn the material cutter, or nitrogen is used to push the excess m be disposed of.

Article	Question	Answer
Laser Focus	**Discussion**	Points that could be discussed: • SSDs will replace optical discs for informati... replaced tape. • Use of CDs, DVDs and ... will diminish ... wirelessly downloaded. • Storing information at the site it is used ... cloud services become ever more popular. • An advantage of using SSDs and cloud ser... the reduced risk of loss of data due to me... • A disadvantage of using cloud services ove... having so much information stored in one ...
...bres	1	
	2	A multi-mode fibre, because multi-mode fibres ... fibres and the effects from modal dispersion ar...
	3	Any one of the following: 1. **Intermodal dispersion**: Different modes ... different speeds, which is why single-mode ... remove this type of dispersion. ... single-mo... however, so the ... multi-mode fibre ... transmission. 2. **Chromatic dispersion**: Different frequenci... ..., although this also applies to EM r... part of the spectrum) travel at different sp... can be sub-divided into two other types o... • Material dispersion: The refractive ind... depending on the frequency of light t... • Waveguide dispersion: The way the ... make the waveguide results in a freq... refractive index, even though the mat... frequency dependence. A pulse of light will have a range of fr... meaning the pulse spreads out with ... of information, as in today's signal tra... to overlap, which becomes a problem ... at 60–70 km intervals along a fibre to ... remove this chromatic ... effe... (coherent light ... same frequen... dispersion. 3. **Polarisation mode dispersion**: Different po... ... different speeds. Polarising the ligh... remove this effect.
	4	1550 nm, because this wavelength experiences ... silica, meaning a signal can travel further down...

Article	Question	Answer
Optical fibres	**Discussion**	Points that could be discussed: Advantages: • no risk of damage or breaka[illegible] to an[illegible] • can constantly cha[illegible] of [illegible]onnect[illegible] Disadvantages: • diff[illegible]ostl[illegible] install and maintain • [illegible] damage from radiation and objec[illegible]
Imaging the Invisible	[illegible]	Fo[illegible] [illegible]mple set-up to photograph schlieren im[illegible] [illegible]pparatus will be needed: • a camera • a laser / pin-point source of light • a knife edge or colour filter • a parabolic mirror
	2	It allows the engineers to see minute differenc[illegible] help the engineers design aerofoils or other ae[illegible] to perform as they require.
	3	Quantum tunnelling is the effect of a quantum [illegible] moving through a potential energy barrier. Thi[illegible] has an associated wave function that is relate[illegible] the particle at a particular position. The wave fu[illegible] further away from the particle's expected positi[illegible] the wave function of the particle spills [illegible]ver the [illegible] chance of finding the partic[illegible] [illegible]her side [illegible] side, the particle has [illegible]ed [illegible]ugh the bar[illegible]
	4	Capillary for[illegible] [illegible]e [illegible]at[illegible] [illegible] meniscus, a bo[illegible] gas [illegible] and air), that creates an attr[illegible] [illegible] connected to. These forces can be r[illegible] [illegible] experiment entirely in a fluid, such as water [illegible] therefore, the water vapour.
	[illegible]iscussion	Points that could be discussed: • Friction, surface roughness and defects cou[illegible] • STMs can image the conductive properties [illegible] design nanostructures. • STMs can manipulate single atoms, so can [illegible] • STMs can be used to design, build and res[illegible] semiconductors. • AFMs can analyse non-conducting objects, [illegible] crystals of amino acids • Imaging the nano-sized biological objects [illegible] understanding and even cures for diseases [illegible]
Meta-magic	1	A metamaterial is a material that goes beyond [illegible] normal materials. This typically mea[illegible] manip[illegible] electromagnetic radiation, [illegible] [illegible]ffects li[illegible]
	2	8–13 μm
	3	The Persi[illegible]s [illegible]d [illegible] shallow bath with wate[illegible] Th[illegible] [illegible]peratures in the dessert at nig[illegible] [illegible]ds), which would cause the water to [illegible] [illegible]allow water would radiate heat into the atmo[illegible] infrared radiation emitted is barely absorbed b[illegible] water past its freezing point.
	4	A negative refractive index means the compon[illegible] parallel to the boundary is reflected, causing th[illegible] back in one direction as it passes through a bo[illegible]

Article	Question	Answer
Meta-magic	**Discussion**	Points that could be discussed: • coating buildings / transport vehicles in the hot climates • use as a heat shield fo[r] su[rrou]nding satellite • keeping fre[s]h pr[o]duce [an]d farms cool • ext[...] the[rmo]s flasks to keep drink
Interferometers: Getting into Superposition	1	[...] the [be]ams are in phase because they o[...] co[her]ent light source. The beams then travel vi[...] superimposing to create a resultant wave. The [...] wave depends on how in phase or out of phase [...] out of phase the beams, the smaller the amplit[ude ...] length of each beam will result in a phase diffe[rence ...] allowing the change in path length to be meas[ured]
	2	The aim was to measure the difference in spee[d ...] arms of an interferometer. The interferometer [...] through the aether, so one arm was travelling a[...] the aether compared to the other arm. If light t[...] relative to this aether, a difference in the speed [...] measured by the interferometer.
	3	Einstein proposed that the speed of light was c[...] observer is. It is space and time that vary betw[een ...] speed of light constant.
	4	They were each approximate[ly ...] masses
	Discussion	Points that could be [discuss]ed: • Better re[sear]ch i[nto] b[lack h]oles could be p[...] [...] holes, making them invisible [...] [...] [co]uld be better research into neutro[n ...] behaviour. • Dark matter is only known to interact with [...] gravitational waves will give us insight into [...] • It could be a new method to back up and [...] electromagnetic telescopes.
[Holo]grams: Seeing Things That aren't There	1	The reference beam is used as a source of light [...] reflected beam from the object. The holographi[c ...] interference will then display an image of the o[bject ...] identical reference beam.
	2	An array of nano-sized silicon discs that can tu[...] computer
	3	To transport parts of a device in the manufactu[...] physically touched To deliver medicine or other medical treatment [...] the human body
	4	The holographic principle s[...] information is stored as deforma[tions] on the surface of the b[...] information [is not] lost, [or destr]oyed, which satisfies m[...] [...]cs.

Article	Question	Answer
Holograms: Seeing Things That aren't There	**Discussion**	Points that could be discussed: • Where is this 2D surface where all informat • Why would the universe be a hologram? • What is the physical meaning of a hologra • A holographic image is projected from a 2I information of our universe is stored on a • ... within our holographic universe is pr • Could there be new unfound physics based • How is the information stored on the 2D su hologram, what is the equivalent of the ref
... to ... World	**1**	Electromagnetic radiation is a wave, so can inte constructive or destructive interference. When modes that don't set up standing waves (waves integer wavelengths equal to dimension of spa cancelling each other out. The waves that do se survive and be the only wavelengths of electro leads to certain energies allowed, hence the qu the confined space.
	2	It states that the system is simultaneously in all observation, such as a measurement, is made o
	3	The analogy describes the state of a cat that is simultaneously alive and dead. It is only when t state of the cat is determined. The analogy app interpretation of quantum mechanics, which sa mechanical system can be in all possible states system ... does it fall into one state. S ... show flawed the Copenhagen interp simultaneously alive and dead, it's either one o we can see it or not.
	Discussion	Points that could be discussed: • For larger systems, all aspects of the syster with each other. • This is essentially an 'observation' by atom collapses the wave form into a larger state. • Quantum effects cancel out at larger scales • Quantum effects only apply to very small s effects can be seen (certain experiments ha quantum effects) • Quantum mechanics is very well studied, so with larger-scale observations for the abov