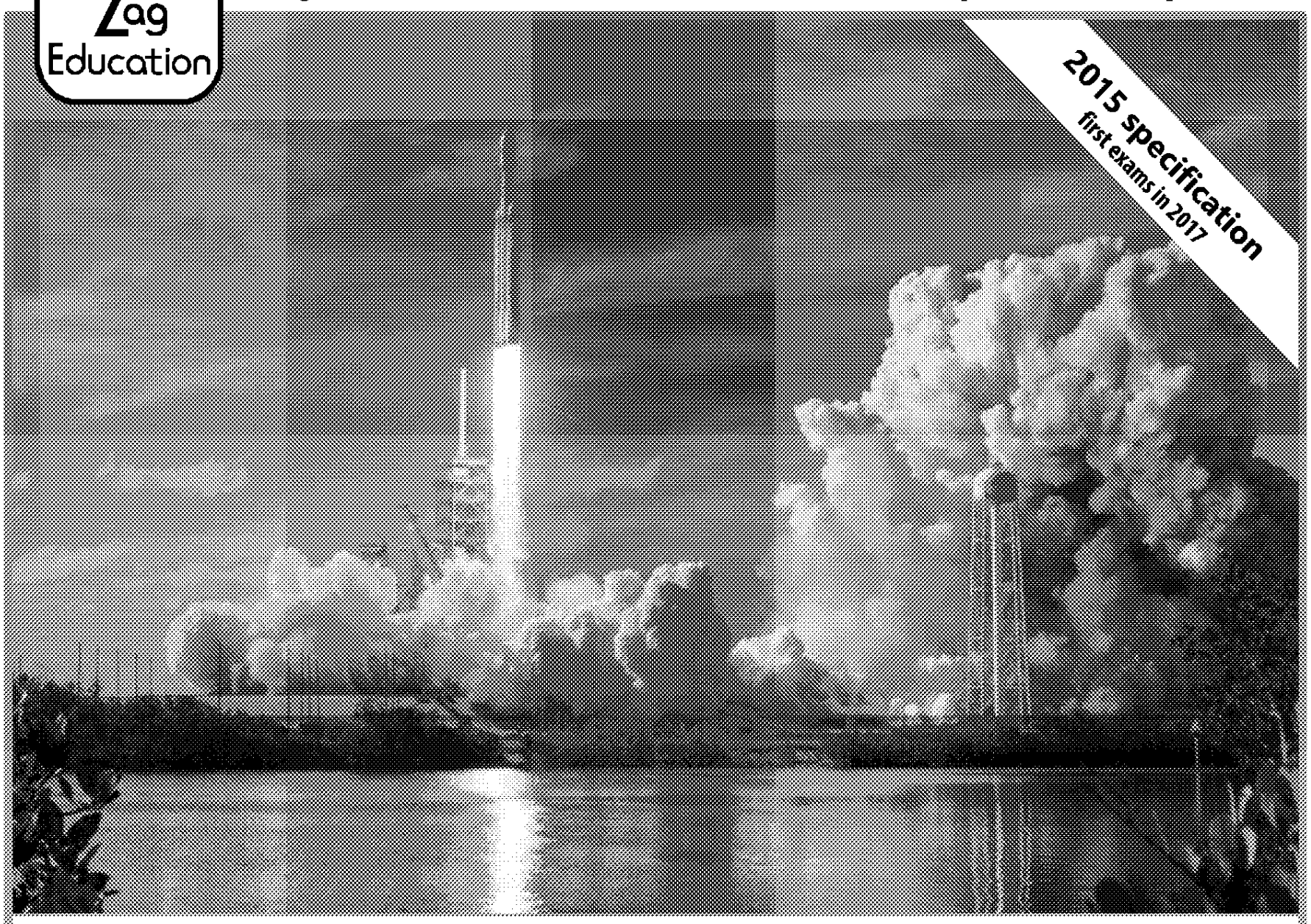
Zig Zag Education

Physics

A Level | Edexcel | 9PH0



Stretch and Challenge Articles

for A Level Edexcel Physics

Year 1 (Topics 1–5)

zigzageducation.co.uk

POD 9614

Contents

Teacher's Introduction

These 'Stretch and Challenge' articles are designed to provide stimulation and new challenges for Physics Edexcel 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 Physics Edexcel 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
- activities which are practical or encourage left-field, creative thinking around a problem
- 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 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

List of articles

Big Engineering: The International S

Topic 2: Mechanics

Keywords	
Monolithic	An object built with one piece
Orbit	The curved trajectory of a[illegible] caused by the gravitational at[illegible] orbits
Module	A self-[illegible]ed unit that combines with other modules to mak[illegible]

Th[illegible]nati[illegible] Station (ISS) is the largest structure ever built by humans in [illegible] the necessary materials into space and constructing the structure in a mic[illegible] dertaking, but is worth the data and experience we gain about living and

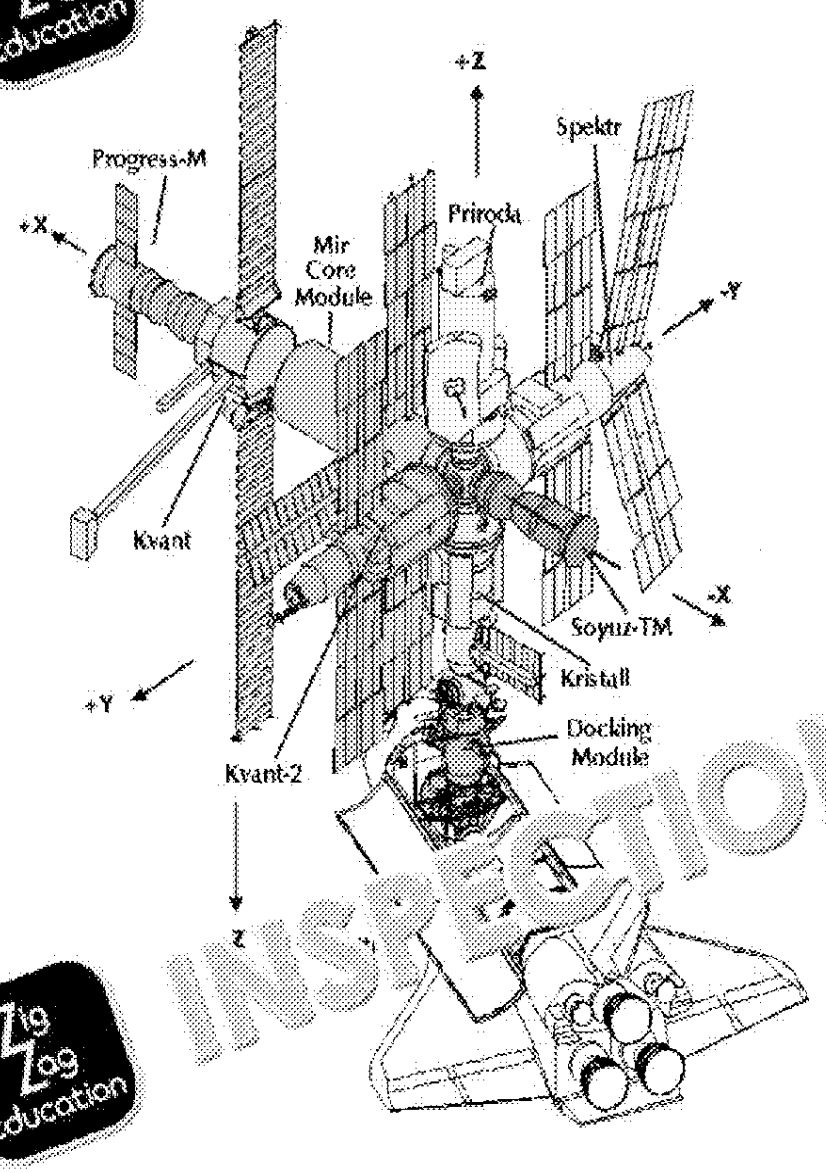
Before the ISS

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[illegible] failed missions only resulted in financial loss.

The last Salyut mission, Salyut 7, stayed in o[illegible]nger than its predecessors, a total of 3216 days[illegible]e[illegible]and 1991. However, it was only occupied by [illegible]16 da[illegible], up until June 1986. Salyut 7 provided the leg[illegible]th [illegible]ansition between monolithic space st[illegible]nd [illegible]r space stations, the type used today.

A Soyuz [illegible] Salyut 1



The space shuttle Atlantis docking with Mir

Using everything they had learn[illegible] the Soviets launched their first [illegible] into low Earth orbit in 1986. Mi[illegible] habitable modules and several [illegible] in space. These modules were [illegible] in orbit using six launches of th[illegible] launch of the American space sh[illegible] module in 1995.

This was the first long-term spe[illegible] human presence – the space sta[illegible] years, twelve and a half of which [illegible] point had a[illegible]o[illegible]ous habitab[illegible] years, the longest such record [illegible] 20[illegible].

Mir was a centre for groundbre[illegible] collaborations between scientist[illegible] UK, France, Germany, Hungary, [illegible] studies took advantage of micro[illegible] positioning, including experime[illegible] space on humans, plants and a[illegible] biotechnologies which were pre[illegible] comparably high gravity; testing [illegible] future missions; astrophysics ex[illegible]

molecules taken from space; and observations of Earth, which allowed monitoring o use, weather systems and natural disasters. But Mir was more than simply a scienti high surrounding the Soviet Union and its collapse, a high-profile scientific collabo cultural barriers was an important symbol of unity and peace.

After the Soviet Union (USSR) collapsed in 1991, the oper[illegible] f th[illegible]ir space stat Russian Federal Space agency (now known as Ro[illegible]nos[illegible] decided to deorbit 1999 due to a lack of funding. Mir brok[illegible]n[illegible] Earth's atmosphere in the early 21st March 2001. How a satellite behaves during its deorbit is very unpredictable be speed trajectory through increasing pressure of Earth's atmosphere introduces making any predictions where the various fragments may end up difficult.

ha[illegible]wo space stations in orbit before the ISS was built. The first was Sky[illegible]nch of the Saturn V rocket (the rocket that took man to the moon). Thre[illegible] b[illegible]en 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 [illegible]t[illegible] Russian Zvezda was added. Since then, another 29 launch[illegible]e t[illegible]up modules and sections built by NASA, Roscosmos, [illegible]ap[illegible]Aerospace Exploration Agency (JAXA), the Canadi[illegible]pace [illegible] (CSA) and the European Space Agency (ESA) t[illegible]spac[illegible]on to be fitted, making the ISS an international coll[illegible]

Th[illegible] pri[illegible]e shuttle Endeavour took the Canadarm2 to the ISS, [illegible]rm built by the CSA that helps with docking and maintenance of [illegible] 8th April 2016, A Falcon 9 rocket launched by SpaceX took the Bi[illegible]ow 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 Januar[illegible] 2018, 230 people from 18 countries have visi[illegible]t[illegible]S. It only has a capacity of six people at [illegible]so[illegible]s[illegible]onauts and cosmonauts tend to sta[illegible]e spa[illegible]e tation for six months at a time. Th[illegible]e[illegible]w[illegible]e[illegible]exceptions, as in 201[illegible]016 w[illegible]r[illegible] Scott Kelly and cosmonaut [illegible]orni[illegible]o both stayed on the ISS for a year. [illegible] has a twin, Mark, who stayed on Earth during t[illegible] 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 [illegible] board the space shuttl[illegible]

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 retur
- Humans grow a few inches taller – without the constant pressure of gravity, as fact, in January 2018, the three inches Japanese astronaut [illegible] Kohei 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 safel
- Although the space station has shielding, cosmic radiation is still much higher i stint in space can raise an astronaut's risk of cancer. Astronauts can even see t report seeing intense flashes of light in their vision while in space, which is passing through their eyes and producing reactions.

There are also some unexpected effects; red blood cell production decreases, c deform and produce eyesight problems, and changes to DNA have even b

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 eyes impairment than men, whereas men are less likely to faint when standing after retur lose less blood in space.

Breaking the ISS

All good things must come to an end and the ISS is no exception. NASA have comm 2025, whereas Roscosmos have endorsed the RC[illegible]il 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. [illegible], 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 Mars 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.

It's Not Exactly Rocket Sci

3.4.1 Force, energy and momentum

Keywords

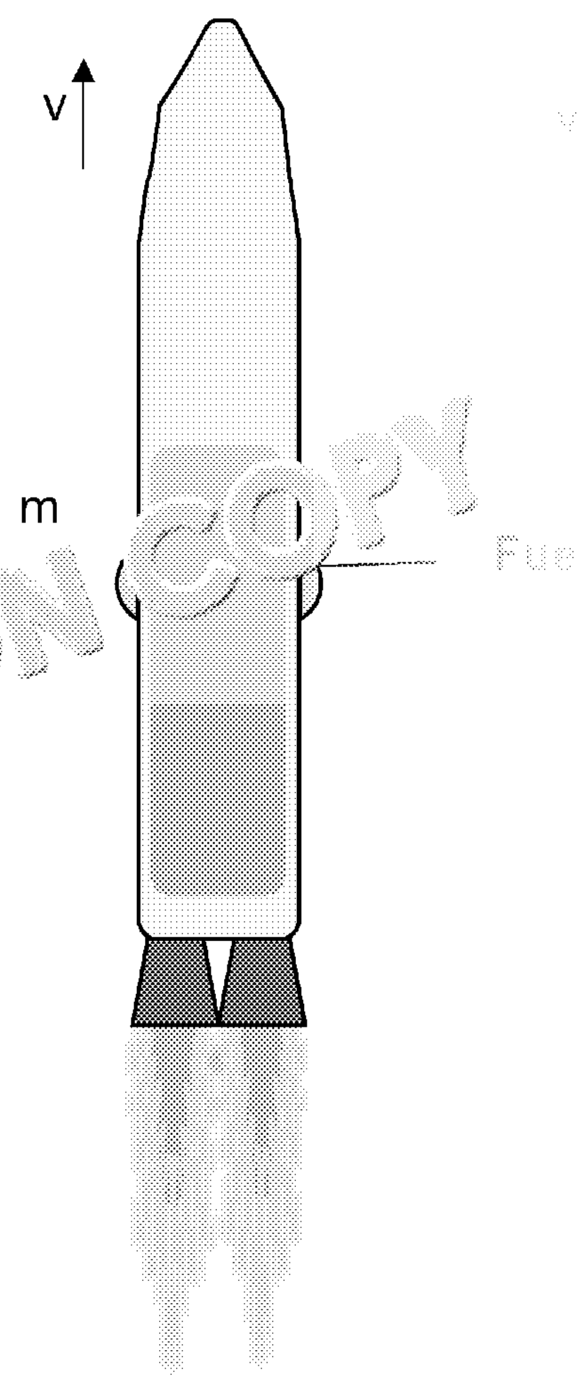
Exhaust gases	The burnt propellant that exit th eng ne or a rocket at high ve
Orbit	The path of an objec as it is v. tionally bound to another ob
Eccentricity	The measure ... ellipse is stretched compared to a

Rockets have t ... space, allowed us to build an array of satellites for comm ...ons, ... us 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.



$t = t_1$

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

To conserve ... the momentum due ...aus... 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):

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.

Ke...
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 $\boldsymbol{\delta m\delta v}$ because we assume the change in mass and velocity is small, making this term negligble. Cancelling other terms gives:

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

This equation describes the relation between $\boldsymbol{t_1}$ and $\boldsymbol{t_2}$. Dividing by the change in time to get a more useful 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 $\boldsymbol{v + v_e}$ is the velocity of the exhaust gases relative to the rocket i.e. how fast the exhaust gases leave the rocket. This is to be a constant throughout the flight. Therefore, our equation says that the change in mass, i.e. the more exhaust gases 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:

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

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

$$v_f - v_i = \left(v + v_e\right)\ln\left(\frac{}{}\right)$$

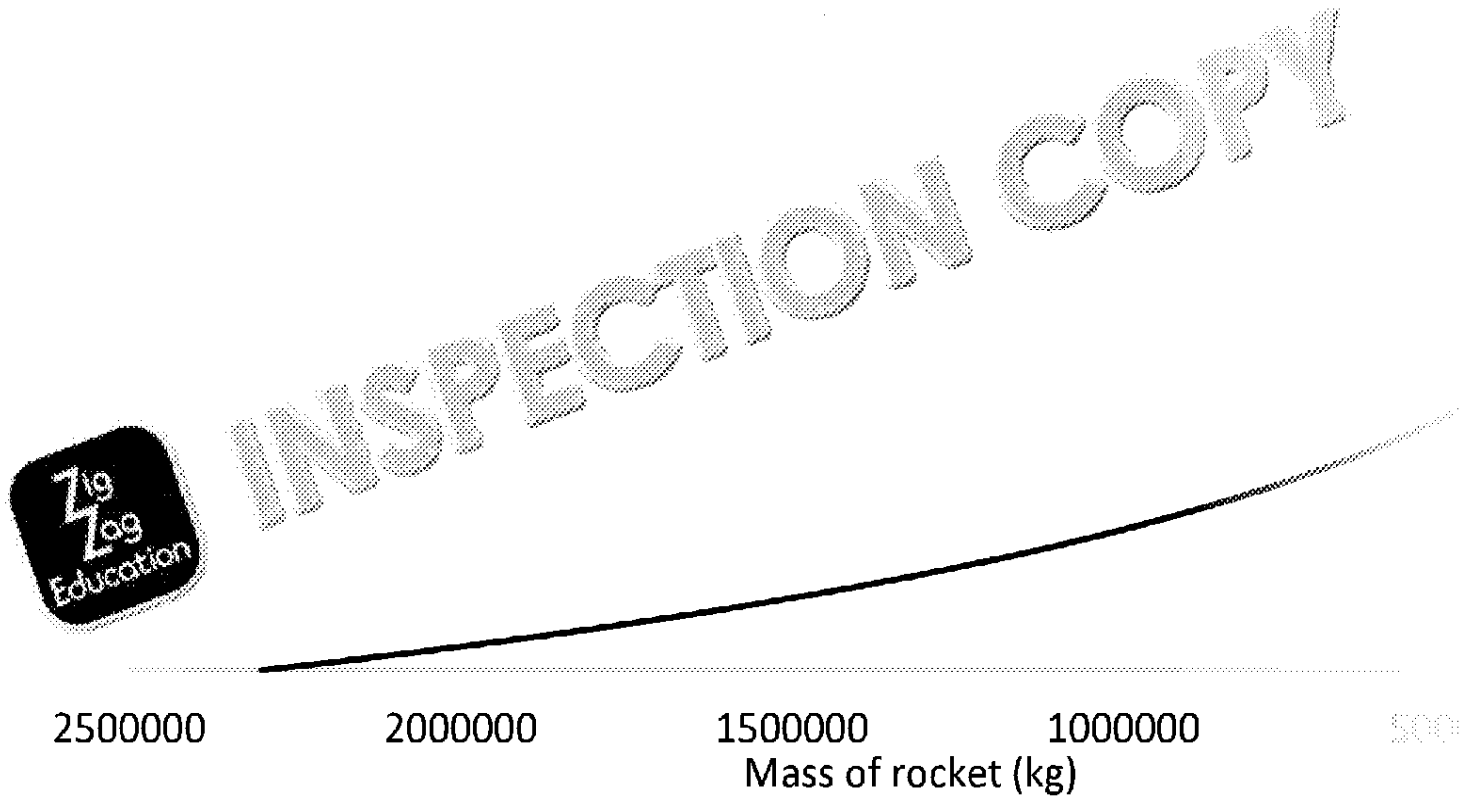
Which gives us the ve
time after some initial
that $v + v_e$ is a consta

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

$$F_r = \frac{1}{2}C\rho A(v+v_e)^2$$

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

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



Orbital mechanics

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

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

The rocket tends to be split into stages. Different engine designs work efficiently at
Once the last stage has deployed the cargo into space, say a new space telescope, it
burns up on re-entry although new commercial rockets land themselves, reducing
the telescope is now in free flight, only acted upon by the Earth's gravity.

An orbit 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, $\boldsymbol{A}$, to a point on the ellipse, $\boldsymbol{C}$, and the distance from the other focal point, $\boldsymbol{B}$, to the point on the ellipse, $\boldsymbol{C}$, is always constant.

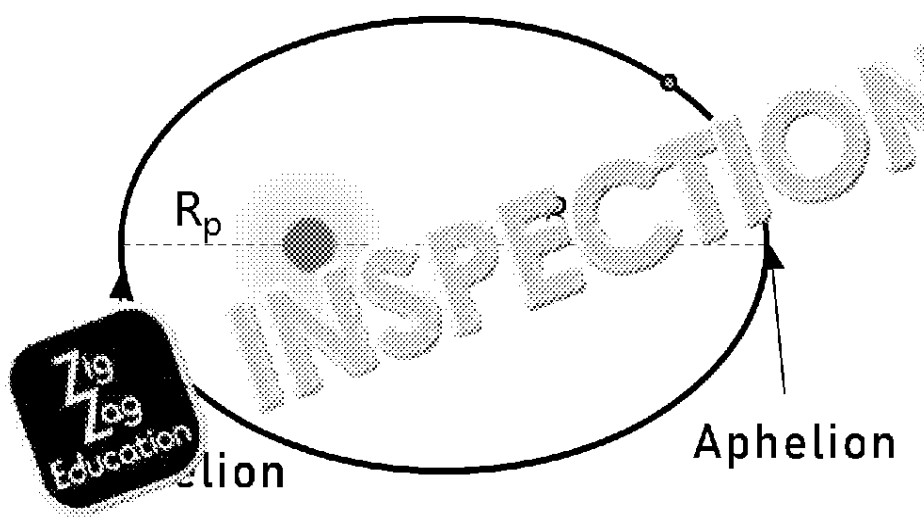
AC + BC = constant

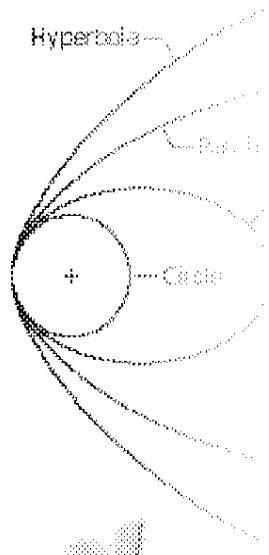
The distance between a focal point and the centre of the ellipse is equal to:

$$e \times a$$

Where $\boldsymbol{e}$ is the eccentricity of the ellipse ($\mathbf{0} < \boldsymbol{e} < \mathbf{1}$) and $\boldsymbol{a}$ 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).





One of Kepler's laws states

$$R_a = a(1 + e)$$

Combining these two gives

$$R$$

Remember a = semimajor

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 into our energy equation gives:

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

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 e
one dep n the
ellip rbit is give

These equations des
of an object can chan
rocket engines on. T
axis and, therefore, t
orbiting object is giv

Where r is the distan
ellipse and the orbiti
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 pe
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 mass of exhaust gases is 7500 kg s^{-1} and it leaves the rocket at 120[illegible] s^{-1}. Wh rocket?
2. State one mathematical property of ellipses.
3. What are the names given to the closest and furthest points of an orbit around
4. The orbit of Mars has an eccentricity of 0.0[illegible] Its semimajor axis is 2.28 × 1[illegible] when it travels through perihelion, 2.00×10^{11} m away from the Sun? The m

Discussion

[illegible] years in the aerospace industry have seen more private companies laun a[illegible]op new technologies, such as SpaceX and Blue Origin with their vertical-la private companies 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 (recall atmospheric pressure decreases with altitude). An alternative is to [illegible] an aer shape throughout the launch to adapt to the changing atmosp[illegible]ssu[illegible]. Resea and write a report on your findings.

Topic 2: Mechanics

Keywords

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

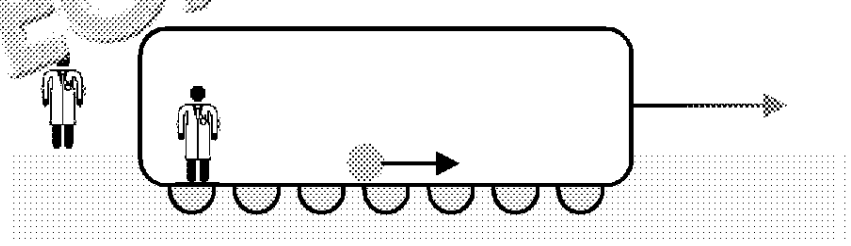
In 1905 Albert Einstein wrote and published one of the most influential scientific pa The paper brought together ideas about space, time, mass and energy, and solved widely discussed problems in physics at the time. This paper, *Zur Elektrodynamik be Electrodynamics of Moving Bodies*, set out Einstein's 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 sealed (no gusts and p can perfectly see everything happening inside. The train travels past the platform at

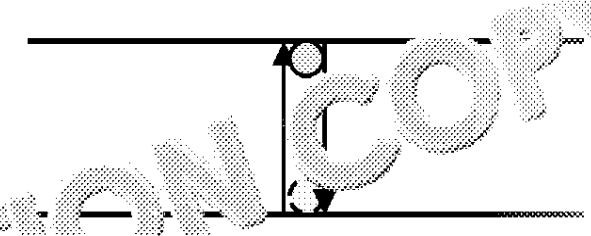
The passenger takes their ball and bowls it down the train aisle in the same direction scientist on the train kindly measures the ball's speed and confirms that it is travelli



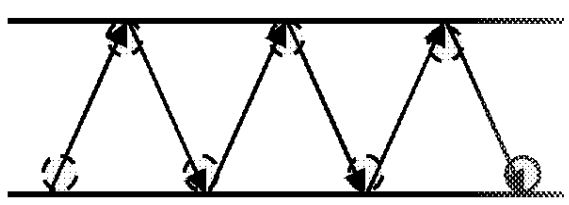
However, another scientist standing on the platform also measures the speed of the because they've measured the speed of the ball added to the speed of the train.

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 t 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 differen
different effects. Neither scientist is more right than the other, they're just measurin
different points.

In fact, all physics works exactly as you'd expect, no matter the r[illegible]e, as l
isn't accelerating. In any reference frame, momentum a[illegible]nergy is conserved, c
fields act exactly the same. If the train were perfe[illegible]opaque with no windows, a p
know the train was moving at all, no matter what [illegible]ce experiments they perfor
sped up, slowed down, or turned corners though they might notice the engine

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

[illegible]lling light

Be[illegible]een 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 l
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. T
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 problem in whic
travel at this fixed speed?

Think back to our train, but instead of rolling a ball 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 and the other should measure c plus 10 m s^{-1}. Maxwell's equatio
special reference frame in which light travelled at its 'correct' speed, in complete vio
[illegible] frames equivalent in terms of physics.

[illegible] for this, the idea of an **aether** was put forwards. This aether was propos
w[illegible]ght travelled at its true speed. Two scientists, Albert Michelson and Edward
experiments in an attempt to measure the effect of the aether. The experiments inv
light in different directions and at different times of the day – depending on the mo
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

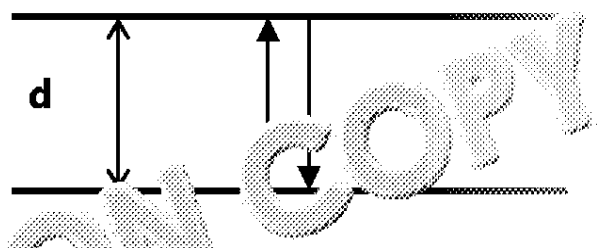
Einstein's solution to this problem couldn't have been simpler, he just accepted that

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

1. In an inertial (non-accelerating) reference frame, the laws of physics are invari
2. The speed of light is constant in all reference frames, independent of the motio

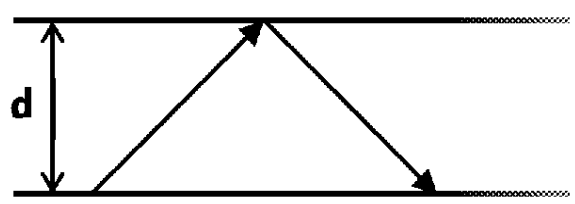
[illegible] as a starting point, Einstein made a startling claim: to account for these t
[illegible]d bend, stretch and squash to accommodate the measurements of differ

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 train sees something quite different, though. Instead of ref
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 photon
train and photon have moved forward by a distance vt.

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

We can even work out by how much the two scientists diff

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

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

The scientist in the train:

$x = d$

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 through yourself?

Now we can isolate t' in this equation:

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

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

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

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

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 noti[illegible] – [illegible] s measured 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] ere it becomes a lot more noticeable. 1 s on the train is measured [illegible] 1.05 s, but at 87 % of the speed of light, the time m[illegible] on the train become[illegible] measured from the platform. For this reason, speeds faste[illegible] be relativist[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] ng it tak[illegible] one end to the other. The scientist on the train measures the length of the rod to b[illegible]

We know already that the two scientists measure different times, so they must also [illegible] scientist on the platform would measure the rod to be 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 appar
has ever travelled, but in the world of particle physics, travelling
day occurrence.

When cosmic rays hit the upper atmosph
muon neutrino, and an electron

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

cay
ng the ground, even if it was travelling at the speed of light. What is
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
lifetime increases.

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

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

Twin peaks

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

Imagine two twin
av
at speeds approaching the speed of light. After a short
th
onger for Earth, just like the photon on the train. The astronaut twin
older than herself.

But wait! Since all reference frames are equivalent, this can be thought of from
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
why?

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

General relativity is another of
allowing similar ideas to
important and
is a
way to integrate general relativity and quantum mechanics
a theory which describes all of physics.

Comprehension questions

1. What are the two scientific principles that were at odds with each other in class 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 for the electron?
3. How can the extended lifetime of a muon in a cosmic ray be explained from the observer on Earth and the reference frame of the muon?

Discussion

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

Extension

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

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 ca[illegible] the length contraction, the ladder should suddenly fit according to an observer at r[illegible] 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

Energy Storage

Topic 3: Electric circuits

Keywords

Generator	A device that turns kinetic ener[illegible]e r[illegible]ation of a turbine, in energy
Inertia	The willingnes[illegible] remain in motion if in motion or r
Charge	The m[illegible]property of an object caused by an imbalance of

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

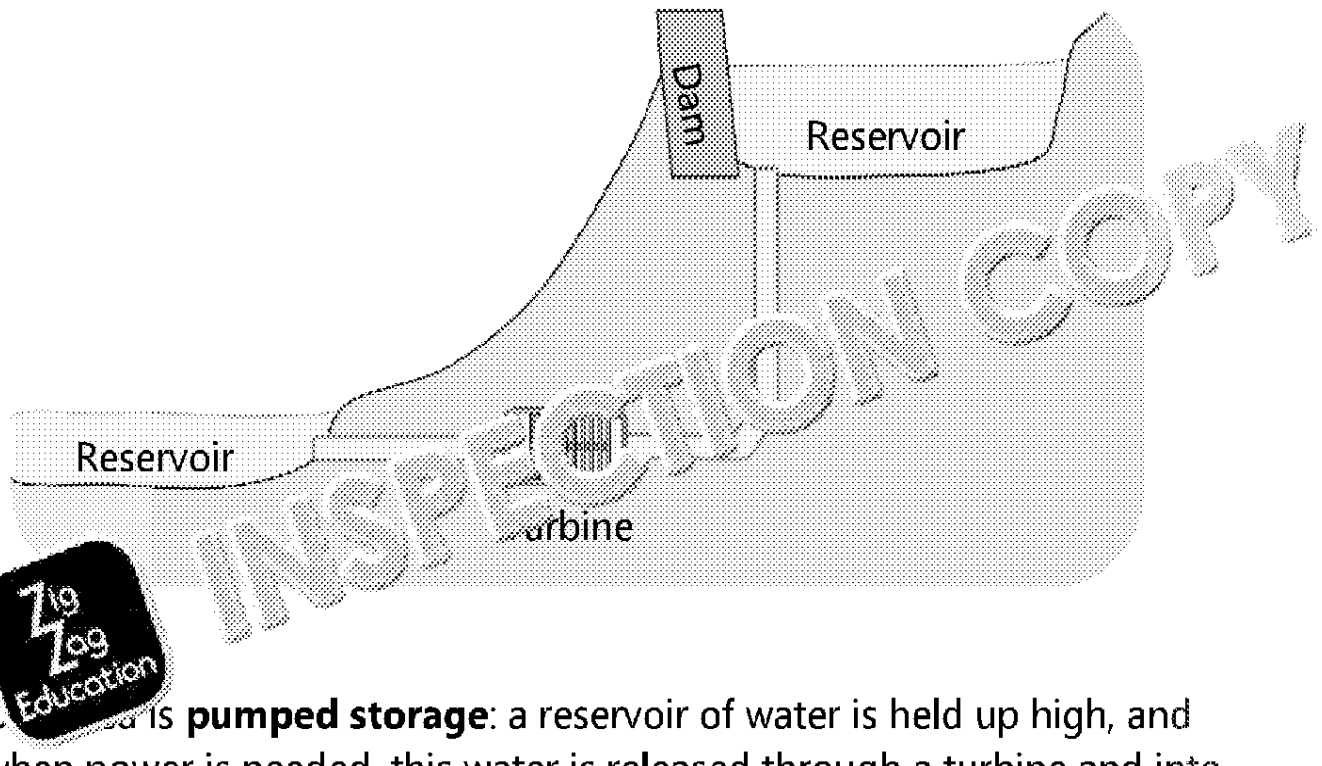
As society moves towards renewable sources which aren't as damaging to the envir resources, the problem may not be generating energy, but storing it. Solar panels n during the day, but what happens at night? What happens to wind farms when it ju windy for the wind turbines to function safely)? And with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

Energy storage in the national grid

Modern life has become dependent on a constant power supply. Without this, our technological infrastructure would power down, reverting us back to the pre-industrial era. Power stations are constantly running to meet demand. However, the demand for power varies throughout the day depending on many factors. In the UK, it is the job of the National Grid to make sure there is enough power in the country all of the time. Any excess power should be sent to other countries, although this is difficult. Ideally, the national grid will store the excess energy to be used at a later point when 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
> same program
> Cup final, Princ
> crucial episode
> end for everyo
> people will go
> resulting in a
> called TV pick
> demand by up

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.



One solution 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

Total p
during

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 reso
reservoir, storing the energy for future use.

The Ffestiniog power station in north-west Wales is a pumped st[illegible] hydroelectric
fastest-responding power stations in the world, being abl[illegible] ne[illegible]t 360 MW of
demand.

Pumped storage power stations d[illegible]t [illegible]rs[illegible]onse times and capacity requirem
national grid; however, th[illegible] th[illegible]fficient. The Ffestiniog power station uses
water back up to [illegible]q[illegible]r[illegible]voir than it generates when the water falls.

oth[illegible]ays to store energy. One such method is thermal energy storage –
mal energy in media such as water or molten salts. These can hold energy
a[illegible]ally used in conjunction with solar power generation to spread out the powe

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 store[illegible] a flywheel is given by:

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

E – Energy
I – M[illegible]ent o[illegible]i[illegible]
[illegible]speed
m – [illegible]ass in outermost section of flywheel

I –

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. B ter s c me in two types:

1. **Primary** – the battery is produced f ll ch g it can immediately output discarded once it's complet s h g
2. **Secondary** – the b ds be charged before its first use. These batter their elect c rea ons are reversible.

ba es 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.

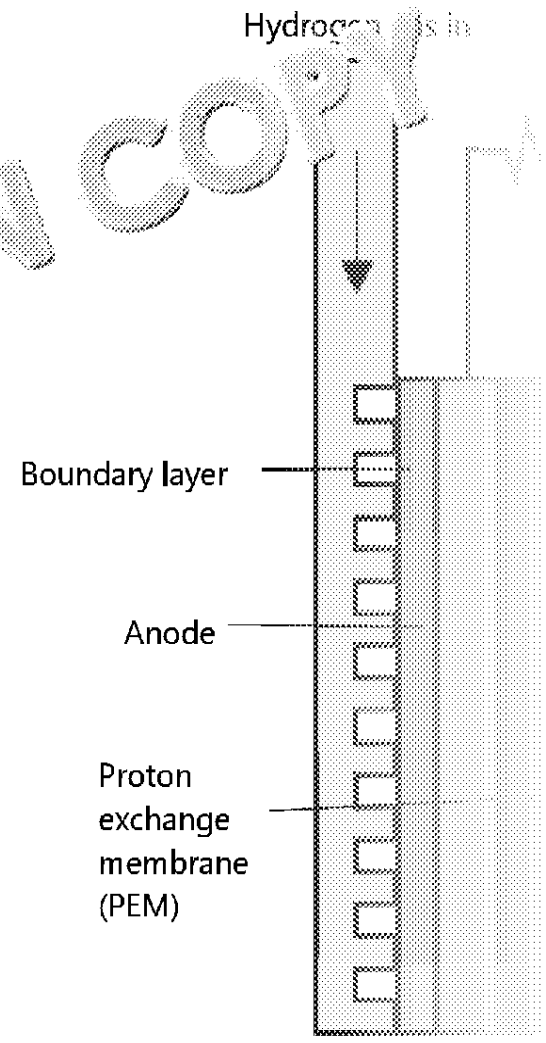
A lithium-ion cell is constructed of an anode (positive terminal) and cathode (negative terminal) suspended in salt solution containing lithium ions (called the electrolyte). When the anode and cathode are connected via a circuit, the lithium ions will be attracted to the cathode, causing the cathode 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 (electron flow into anode) causes the lithium ions to flow back to the anode, charging the cell once more.

Battery technology has drastically improved i e, ea sulting in applications portable batteries and power grid st g l co i g ever more popular. In the UK developing battery storage i a ructu under the enhanced frequency response contract was to buil a y ca that can store energy for short periods of tim supp the n t g . he first completed project was E.ON's Blackburn Meadow atte a on can supply the national grid with power in less than a second umped storage solutions. Many of these projects have caused the natio r crease, 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 boundary layer next to the anode causes hydrogen molecules to split into hydrogen ions (two protons) and two electrons. 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 main problems to favour charging and storing energy in batteries to power electrical vehicles, rather t

Capacitors

A capacitor is a quick way to store electrical energy. Two electrodes are separated by an electric field for a short time. The capacitor is charged when a potential difference is applied until the capacitor reaches a critical point, where it then discharges. The capacitance (the charge it can hold) is measured in farads, F, and a typical capacitor has a capacitance to charge for several seconds.

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

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. Due to the short discharge time of these capacitors the information stored would quickly be lost. Therefore, DRAM uses a separate refresh circuit to keep the information. **Static random access** (SRAM) instead uses supercapacitors which can hold information for much longer. A separate refresh circuit is, therefore, not needed, which makes the RAM much faster to respond.

The principle of regen... the kinetic energy of a ... do ... an use... dissipate this kinetic ... can be used to power ... overall efficiency of the ... the electric motors on ... absorbing the kinetic ... generating power that ... system. **Kinetic** energy ... also installed in cars ... Formula One in 2009. ... stored in a flywheel or ... discharged in later ...

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 region of 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 and SRAM.

Discussion

A private company wishes to generate its own electricity on-site to completely disconnect from the grid. It will generate its power using an array of solar panels and a wind turbine. The power output from these sources varies a lot and doesn't match their demand. Research what solutions 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 it works to your classmates. To aid with the explanation, draw a diagram of a hydrogen fuel cell and

Fluid Dynamics: Going with t

Topic 4: Materials

Keywords	
Fluid	A substance that easily flows and is susceptible to external force
Viscosity	The measure of resistance to internal forces by a fluid due to in
Fluid packet	A piece of a fluid with constant mass but changing volume and s

A fluid is a substance that has no fixed shape but instead can flow and take the shap pl[illegible] all fluids. Fluid dynamics is the study of fluids as they chang[illegible] variables involved in such a system makes it a very complex branch of ph[illegible] l[illegible]e of applications; from aerospace and marine engineering to rocket scien[illegible] 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[illegible] 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 fluid packets fluids) interact with each other. There are three equations, [illegible] spatial
3. **An energy equation**. Called the Bernoulli equation, this e[illegible]s that energy i[illegible]

The Navier–Stokes equations

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

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

The Navier–Stokes equation describes fluids with Newtonian viscosity; any force will the rate of change of velocity at the point, i.e. Newton's 2nd law. Most fluids have N[illegible] 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 pa[illegible] (also called fluid parcels). These are very small 'pieces' of fluid with constant mass but which can have a changing volume and shape. The Navier–Stokes equation describes how all these fluid packets interact with one another.

Based [illegible] custard [illegible] m/wat[illegible]

For simplicity we will only consider the Navier–Stokes equation in one dimension. It [illegible] in the x-direction:

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

Note: The x direction is chosen to be in the horizontal plane, so gravity does not pla
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 tim This is called the **temporal derivative te** ra makes the equation dynamic (changing wi time
$\frac{\partial v}{dx}$	Partial derivative of ve ty with respect to position, x.
$\frac{\partial p}{\partial x}$	a derivative of the pressure with respect to ion, 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 t
dimension are all dependent on each other.

The nondimensionalised Navier–Stokes equatio

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

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

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 viscou h is the

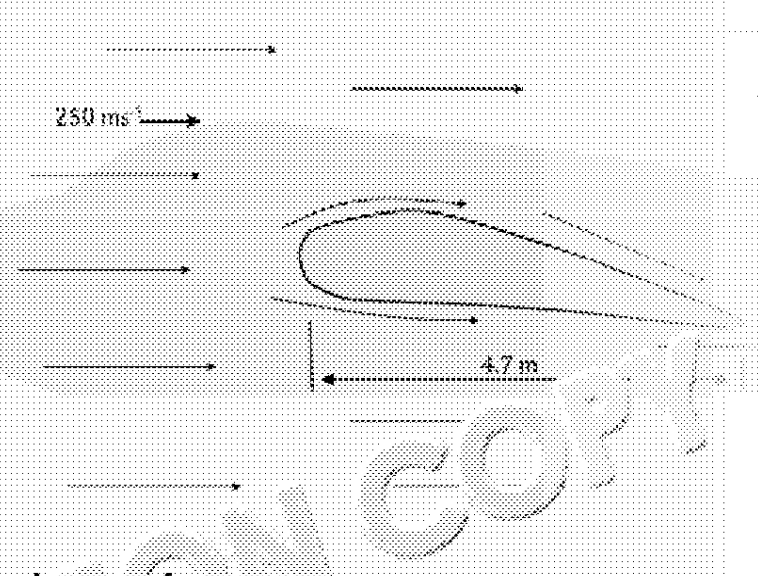
> Inertia is the property of an object to keep moving if it has velocity initially, therefore, the drag an object exerts on other objects is its resistance to its motion (think of a boat pushing through snow).

The Reynolds number

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

Example

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



The Reynolds number in this cas[illegible]e fo[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]umber is really large, meaning the fluid flow will be turbulent around the [illegible] of the Reynolds number, $\frac{1}{Re}$, determines how much the inertial term con[illegible] equation. For this plane wing the term is negligible (viscosity forces dominate i[illegible]

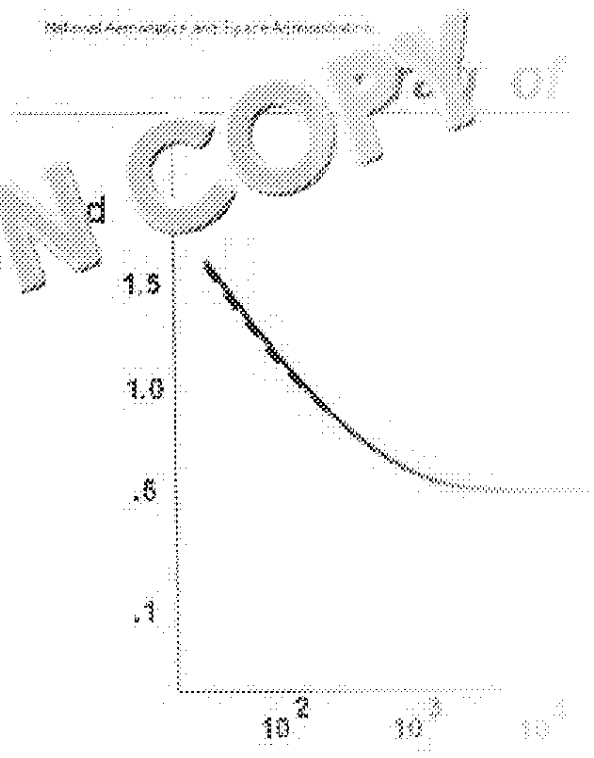
Dragging on

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 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 drag 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 above mentioned theory has a strong basis in many fields of research and development. Some of these theory are described below.

Weather prediction

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

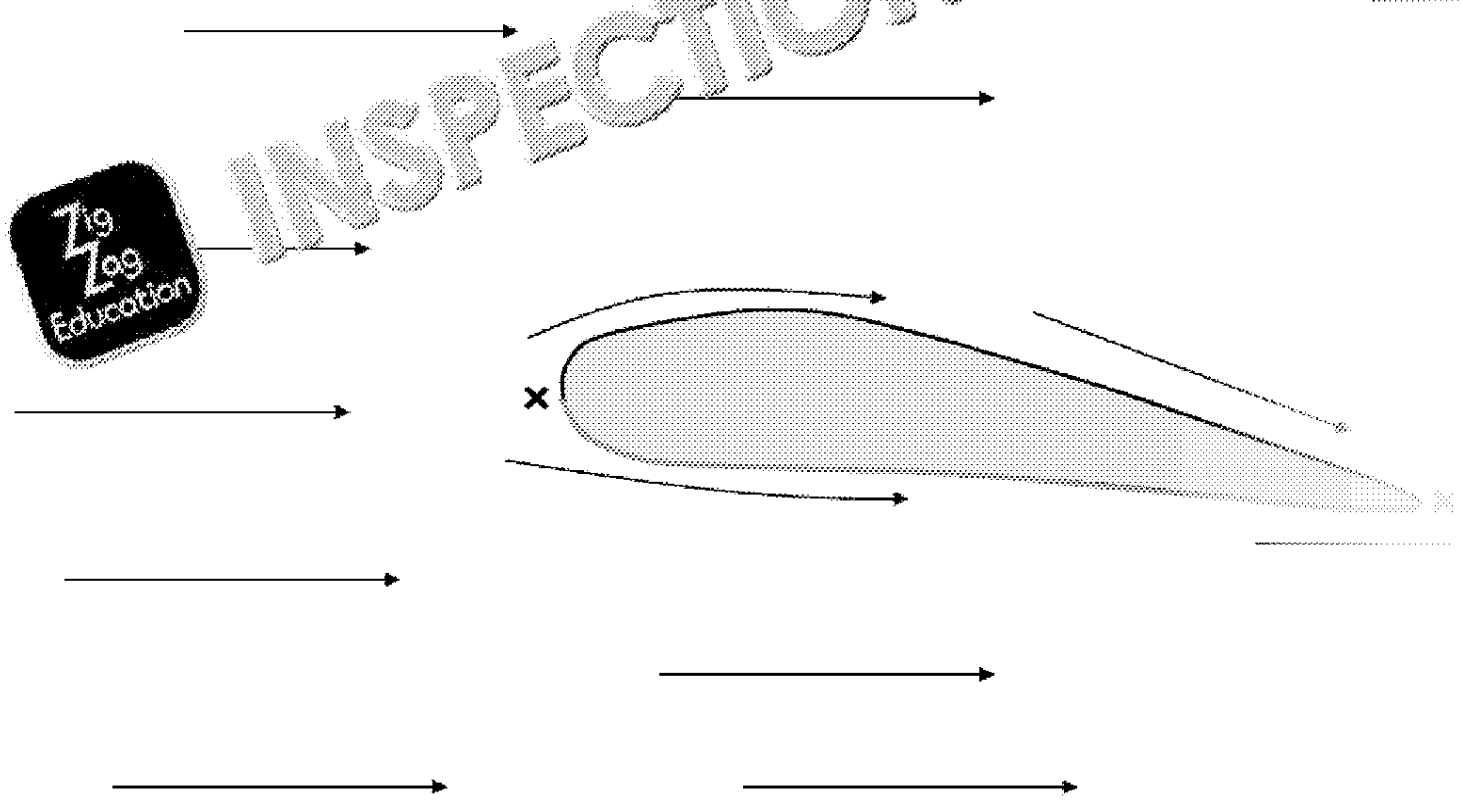
Fluid dynamics, mainly the Navier–Stokes equation, can be used in conjunction with other theories to predict the possible future states of the weather for a certain place. The most likely outcome can then be used to warn people in that place.

The primary goal of predicting the weather isn't just so we can decide what clothes to wear. Predicting any changes that could lead to natural disasters (such as storms, tornados, typhoons, or even changes that lead to increased risk of forest fires), for example, and getting a warning out to the right people in time for the correct precautions being taken, can ultimately saving lives. Weather prediction also allows people to take precautions before the weather changes, increasing their yield and improving the efficiency of their work. Pilots also use weather predictions to plan their route so as not to be caught in storms, reducing the risk of accidents.

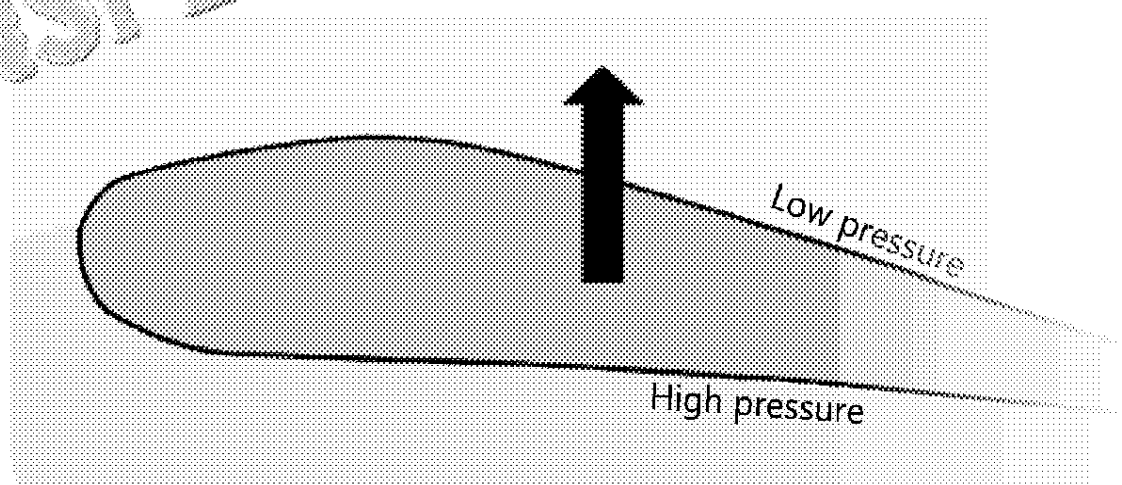
Aerofoils and hydrofoils

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 hav 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 or to 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 in
difference in speeds of the two parts of the fluid, therefore, creates a pressure differ
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 hull 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 Reynolds number of
3. A rocket is part way through its launch at an altitude of 28 [illegible] density of a 2.46×10^{-2} kg m^{-3} and the rocket is travelling at 1.8 [illegible] m s^{-1}. If the rocket has a [illegible] and a drag coefficient of 0.15, what is the drag force acting on the rocket at this
4. Describe how a foil produces upthrust when it is subjected to a flowing fluid.

Discussion

[illegible]e importance of funding research into chaotic systems, such as fluids, if the [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 boa[illegible] other use of foils and present your findings as a factsheet about the application.

Interferometers: Getting into Su

Topic 5: Waves and the particle nature of light

Keywords

Superposition	The interference of two waves that either add or subtract from e resultant wave
Relativity	The idea that the physics of a system can depend on the relative and
Space-time	A four-dimensional continuum that comprises of three spatial dimension.

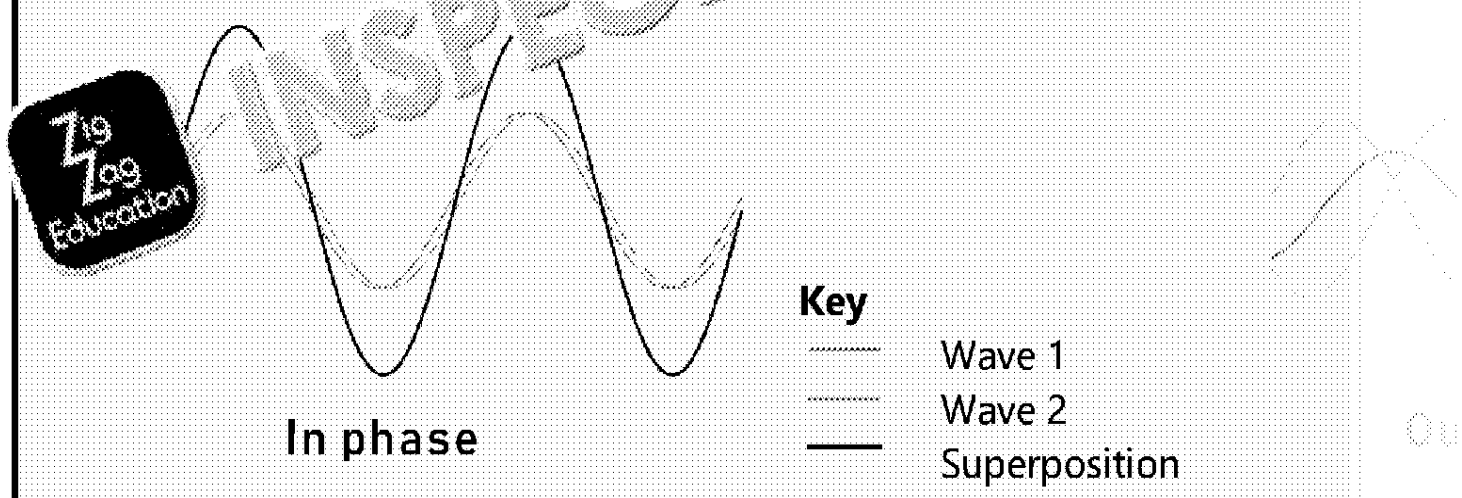
An interferometer is a tool that measures the intereference between two waves. Th extremely small changes in distances, useful in many scientific experiments.

Basic principles

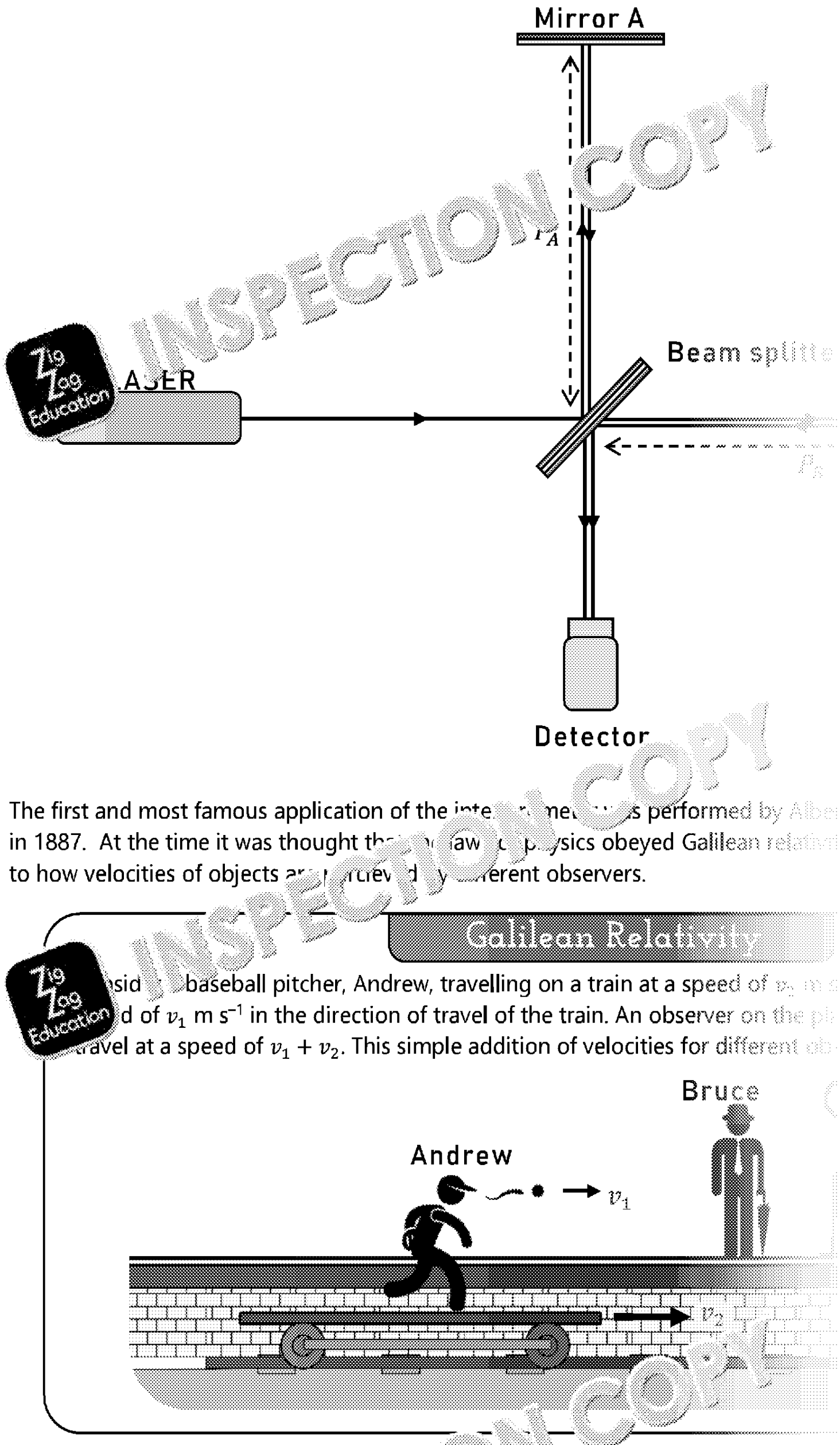
The linear interferometer is the simplest form of interferometer. Devised by Albert device shines light at a beam splitter, creating two beams, A and B, that propagate These beams reflect off mirrors and return to the beam splitter.

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 the path ler different they return to the beam splitter and interefere out of phase. The measure therefore, be smaller due to waves destructively interferi g.

The superposition of two waves that are initially in phase produces a wave with mu superposition of two waves that are initially 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 ch can be measured.



The first and most famous application of the inte[illegible]s performed by Alber in 1887. At the time it was thought tha[illegible]aw[illegible]physics obeyed Galilean relativi to how velocities of objects are measured by different observers.

Galilean Relativity

Consid[illegible] baseball pitcher, Andrew, travelling on a train at a speed of v_2 m s[illegible] 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 ob

During the nineteenth century, ph[illegible]s thought that just like the way sound wave must propagate through a medium called the 'aether'. Also during the mid ninete calculated that light [illegible] ga[illegible] at a constant speed.

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[illegible]fferent. 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 ha 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 tha 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 interference 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 led 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 applies 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 gives elevator starts accelerating upwards at $g = 9.81$ m s^{-1}, the weight would instead read 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 for 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 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 ripp 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 the

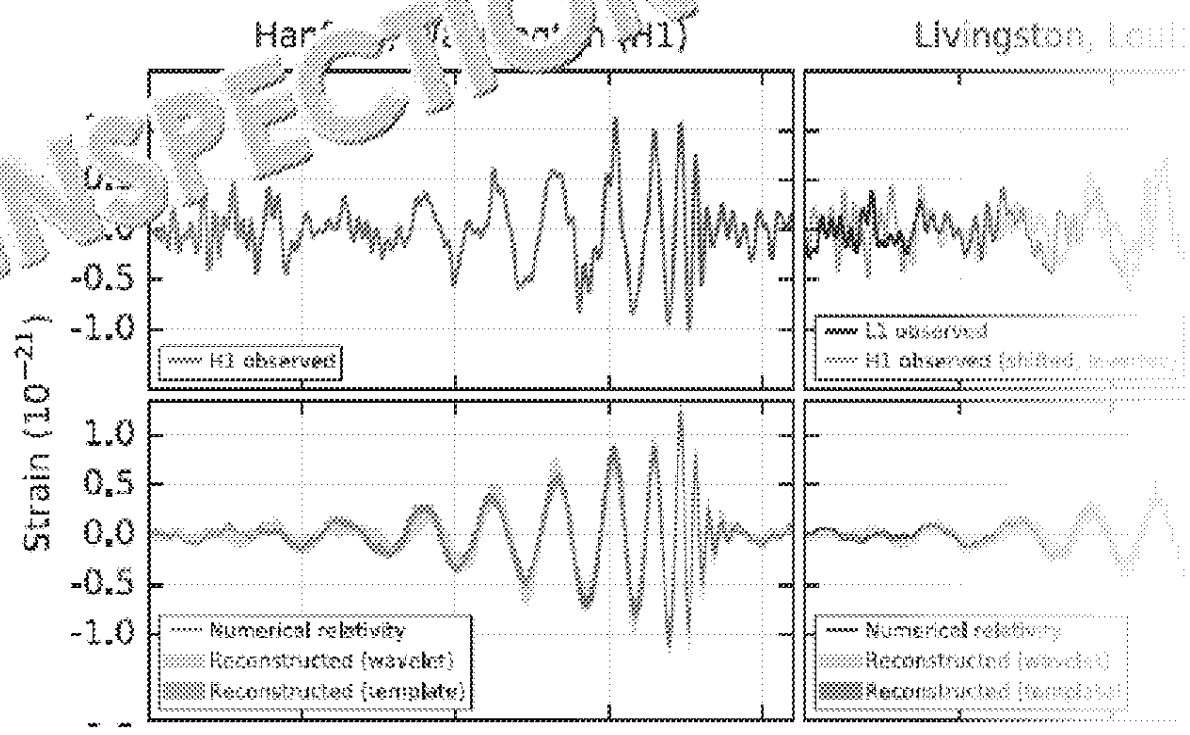
The Laser Interferometer Gravitational Wave Observatory (LIGO) is designed to do e consists of two interferometers situated 3000 km apart in the USA. By using two inter source of the gravitational waves can be deduced.

Each interferometer has arms that are 4 km long (50 times longer than the interferometer used by Michelson and Morley). At the end of each arm are 40 kg mirrors suspended as part of a four-segment pendulum (a pendulum hanging fr a pendulum that is 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 m ms.

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. This

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 d[illegible]tion sit
gravitational wave. It was created by the merging of two 30 M[illegible]s the mass
1.3 billion light years away (this means this event happen[illegible]billi[illegible]ears ago, a
after turning the interferometers on!). Below is th[illegible]s[illegible]na[illegible]let[illegible]cted 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[illegible]ate 20

The European Space Agency hopes to build its own gravit[illegible]de[illegible]or – an spac
Antenna (LISA) will work on the same principles as LIGO [illegible]t wi[illegible]e arms 2.5 milli
contend with interference caused by vibrati[illegible]her sources, making LISA a b
smaller and lower-frequency grav[illegible]a[illegible]ve

Comprehen[illegible]questions

1. [illegible]in h[illegible] the interference between two beams allows an interferometer to
[illegible]es in distance.
2. [illegible]t 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 gravita

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 LI[illegible]on, [illegible]proposed set of satel
position themselves to form a huge i[illegible]me[illegible]t will differ from a standard line
three spacecraft, arranged in[illegible]ngle[illegible]sides that are 2.5 million km long. Desig
be used in a science[illegible]on.

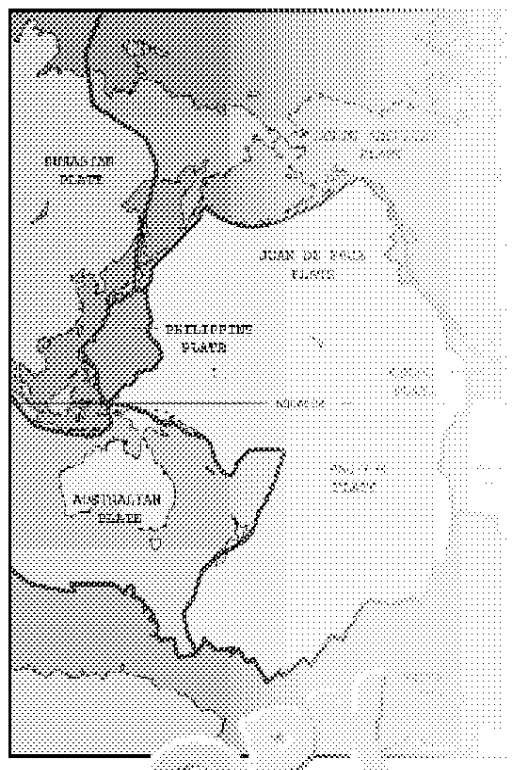
Earthquakes: Shaking Thin

Topic 5: Waves and the particle nature of light

Keywords

Seismic waves	Waves that travel through [illegible]
Attenuation	The reduction in [illegible] wave as it travels through a [illegible]
Plasma	The fourth [illegible] where atoms are partially or fully [illegible]

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



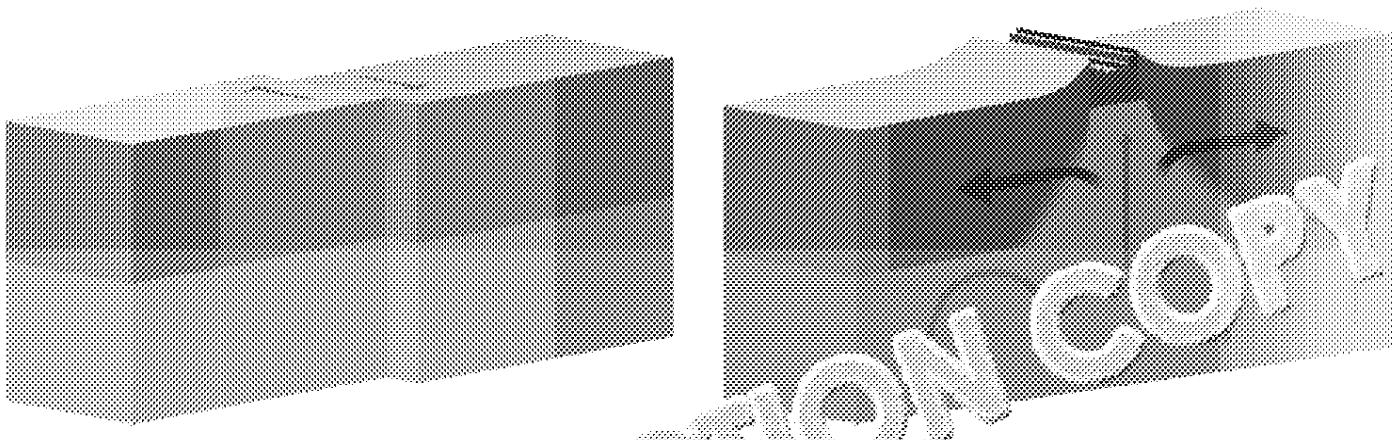
This outer layer is split into plates (like puzzle pieces) that move around due to convection currents in the mantle – a thick layer of magma around the Earth's core. These plates are budged up tightly to one another, with high friction coefficients. When the stress becomes too high for the plate boundary (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 ones. The way plates [illegible] be categorised into three ways:

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

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

Convergent boundaries result in a less dense plate sliding on top of the more dens[illegible] dense plate down into the mantle. This can lead to the construction of mountain ra[illegible] also to strong earthquakes.



1. Transform bounda[illegible] 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 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:

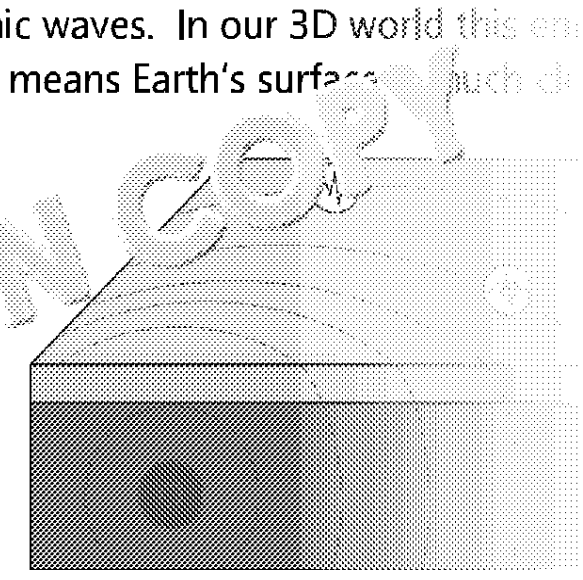
$$E > 10^{1.5M_W + 11.8}$$

which for the Northridge earthquake is an energy of:

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

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 Bomb Richter scale, a medium-level earthquake.

Most of this energy is used to deform rocks or cause heating near the epicentre (so 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 such d 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 three These seismic waves can be split into three parts, each arriving at a detection point at different times due to their nature. They are:

1.
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 h 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 oscillate due to movement in the vertical direction, moving the heavy weight up and down relative to the paper, drawing these oscillations on the moving paper. By having three of these oriented for each (x, y and z), the 3D motion of the ground at a detection point can be determined. Modern seismographs use digital sensors to detect motion, providing much more accurate data.

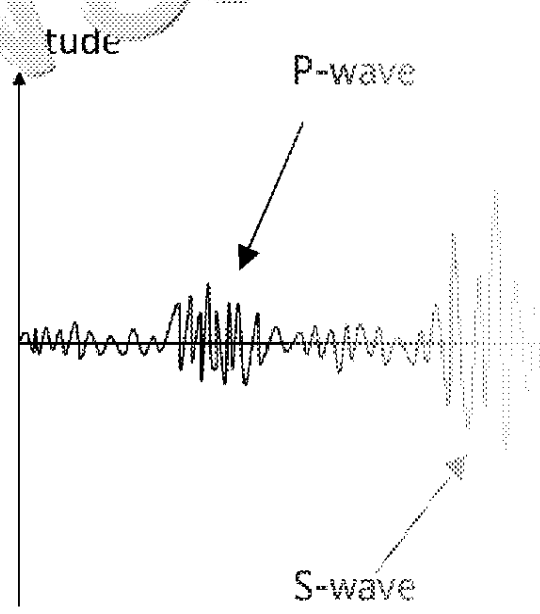
A simple seismograph recorded during an earthquake is shown below. The first pulse is the arrival of the P-waves, then come the S-waves, and finally the majority of the energy of the earthquake hits the detection point as the surface waves.

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.

Did
A seis
heavy
place
seism
much
seism

Replacing the seismograph

Nowadays, seismographs are digital and much more sensitive than the mechanical apparatus described above. However, they are not the only method to detect earthquakes. The movement of tectonic plates constantly emits extremely low frequency (ELF) electromagnetic radiation. The plates 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 opposed to 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 oscillat[illegible]in the
a plasma, unlike the rocky Earth, so the waves propagate differ[illegible]th researc
applications in the containment of plasmas in fusion reac[illegible]rs a[illegible]d p[illegible]cting solar fl
communications here on Earth.

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

- **P-waves**
  Similar to the[illegible]s th[illegible]travel through Earth, these are fast longitudinal wa
  Sun.
- **[illegible]ves**
  [illegible]caused 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 earthqu[illegible]ich [illegible]easured to
   moment scale?
3. What fact, other than the arrival tim[illegible]s [illegible]f t[illegible]types of seismic waves, is us
   the epicentre of an earthqu[illegible]ar[illegible]
4. Describe the future[illegible]ual[illegible]prediction.

Di[illegible]sic[illegible]

[illegible]ether it is more important to invest money into researching geoseismolo
th[illegible]gh 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

Holograms: Seeing Things That a

Topic 5: Waves and the particle nature of light

Keywords	
Laser	A device that emits coherent l[illegible]h[illegible]at a[illegible]re[illegible]e[illegible]requency
Lens	A transparent object [illegible]re[illegible]s[illegible]ht in a way to converge or d[illegible]
Interference	The superpos[illegible]t[illegible]es when they propagate through t[illegible]

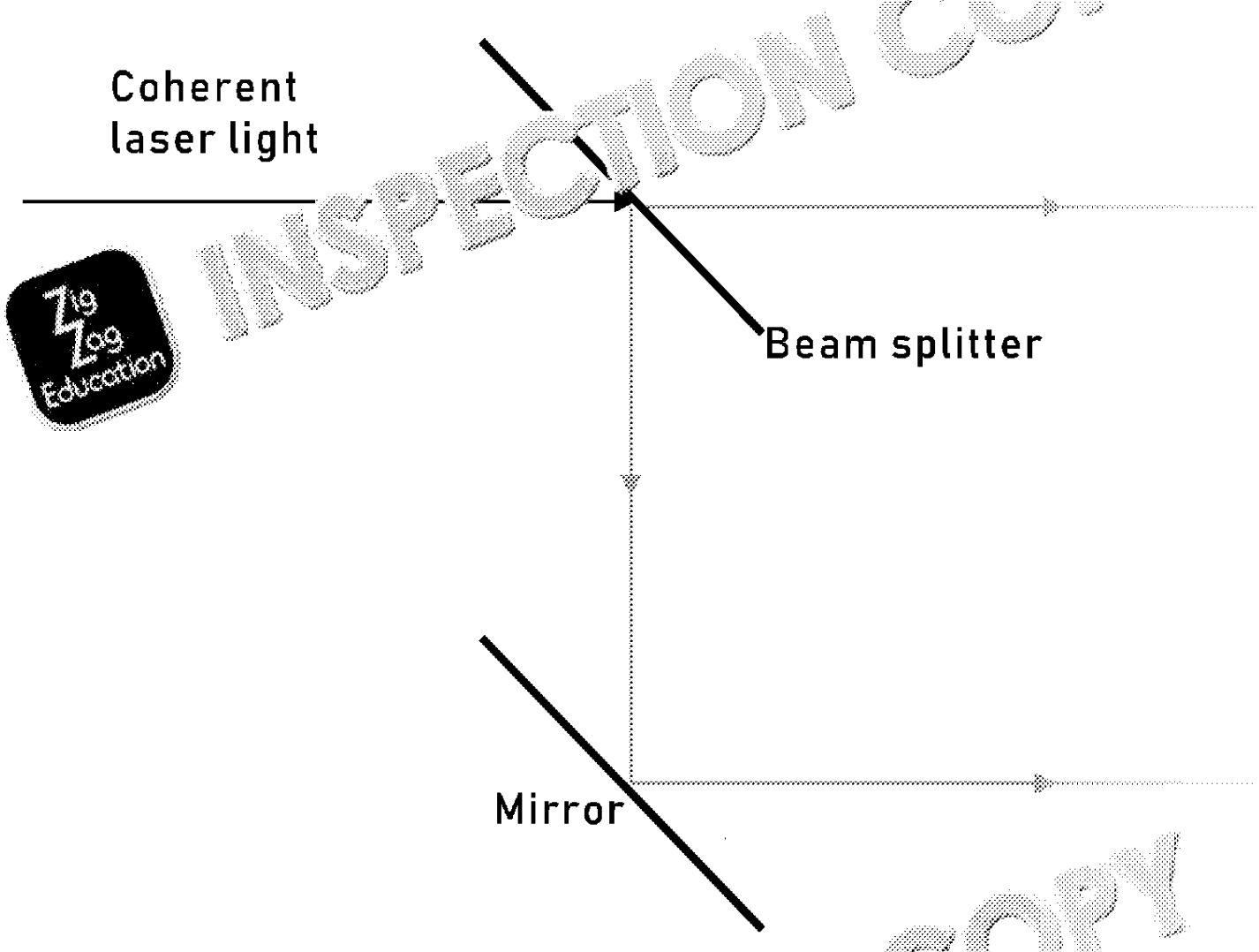
In Greek, holo[illegible]ple and -gram means 'message', so a hologram is a whol[illegible] [illegible]d i[illegible]'[illegible]ologram' has been used to mean a message or image created [illegible]ppears to float in space as if a real object was there. This illusion can be [illegible] [illegible]he most 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[illegible] the holographic plate using a mirror. This second beam is known as the reference b[illegible]

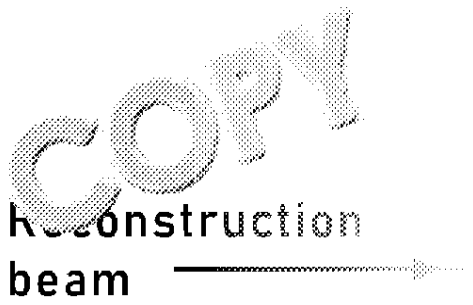
The two beams meet and interfere at the holographic plate. Their interference patt[illegible] holographic plate, just like the way a camera takes a picture by exposing a photogr[illegible]

The pattern recorded on the holographic plate doesn't look like the [illegible]ct[illegible]the ne[illegible]



information to display a 3D image of the ob[illegible]is[illegible]ded[illegible]this pattern. To displ[illegible] holographic plate must be illuminat[illegible]a[illegible]ase[illegible]ight identical to that used to reco[illegible] reconstruction beam either [illegible]mits th[illegible]gh or reflects off of the holographic plat[illegible] an observer.

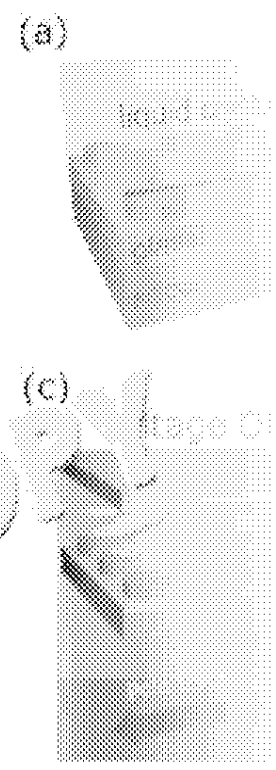
The emerging wave front from the holographic plate is exactly the same as if the object was actually there. Therefore, optical manipulation such as placing a lens in the path of the wave front will magnify the image of the object, just as if the observer was looking at the real object through the lens.



A common example of reflecting holograms can be found on credit cards or passports. These holograms are hard to reproduce, making fraudulent [illegible] more difficult, 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 through the discs so the later interference produces a holographic image. The sites are controlled electronically so can switch on and off in quick enough succession to produce a dynamic hologram.

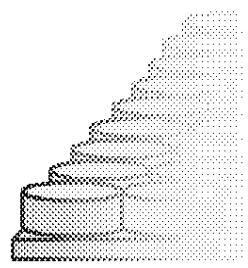
The Star Wars-esque dynamic holograms won't be replacing our video calling any time soon as the primary method of communciation.

Acoustic holography

Holograms aren't specific to light. Any wave can be used to create a hologram, including sound. The process works slightly differently to laser holography. The basic principle is to produce two sound waves that interfere to create a pattern of pressure variations in the medium in which they travel.

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 application of levitating small objects. The object gets stuck in the pressure well, with high pressure air surrounding it. The force due to these high pressure areas is strong enough to counteract the weight of the object, and any small perturbations by the object, keeping the object in place. This application 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 can be stored on an $(n-1)$-dimensional **holographic principle**.

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

aphic 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 mechan 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 experimental 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 wh 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 report

Laser Focus

Topic 5: Waves and the particle nature of light

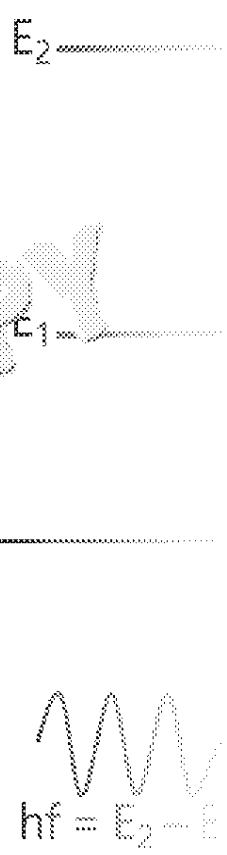
Keywords	
Ground state	The lowest possible en[illegible] stat[illegible] particle. Note that th[illegible]
Energy transition	The gain or lo[illegible] en[illegible] a particle, causing it to tran[illegible]
Optical resonator	The pa[illegible] re light resonates and amplifies, [illegible]

Fundamental principles

[illegible]on in an atom has an associated energy level. These energy levels are di[illegible] [illegible]n electron is only allowed to have energies that correpsond to these ener[illegible] 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, [illegible]absorption[illegible] where an electron in a low ener[illegible] state [illegible]s by [illegible]coming photon to transition to a higher [illegible]te (the opposite of spontaneous emission). The incident [illegible]st have the exact same energy as the energy difference b[illegible] the low and high energy levels, otherwise the photon will just miss the electron without interacting with it.

Stimulated emission

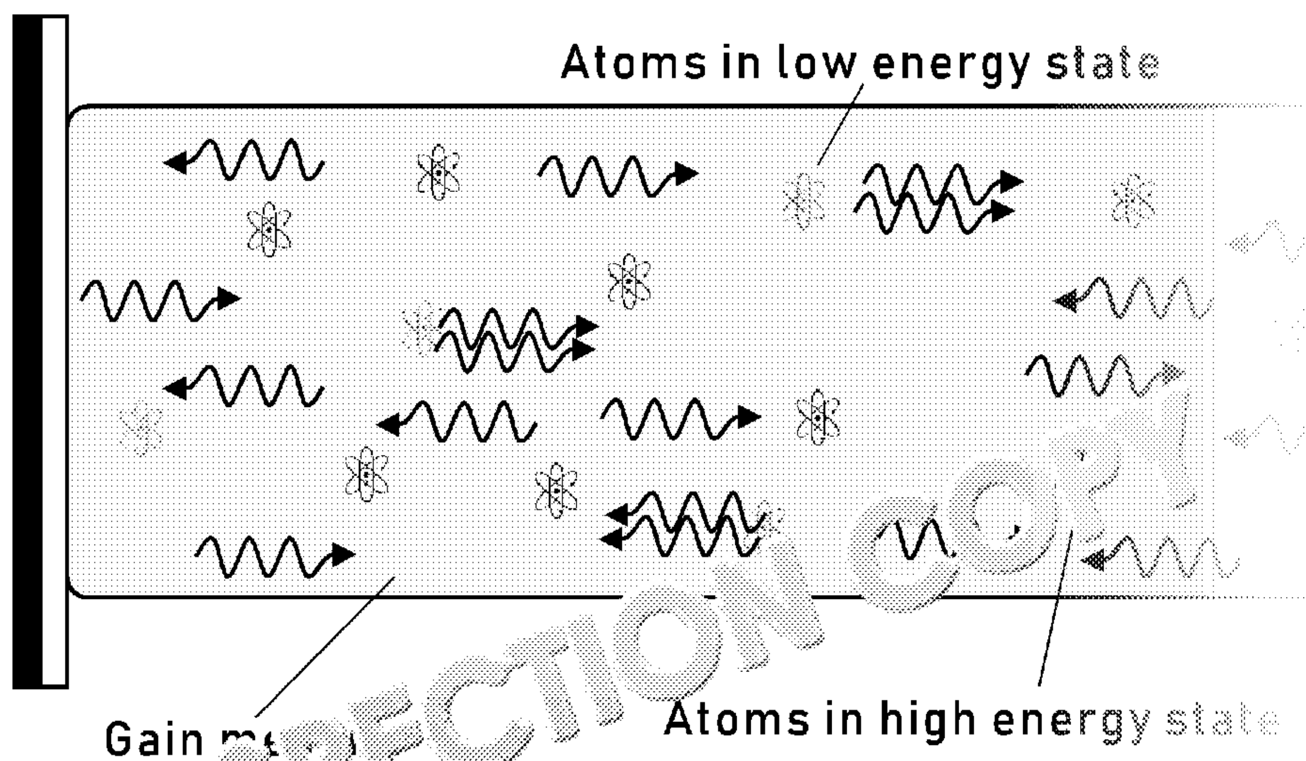
Consider an electron in a high energy state, as for spontaneous emission. If an inc[illegible] equal to the energy transition ($E_2 - E_1$) comes along, the photon will interact with t[illegible] to transition to the lower energy level. The change in energy causes a new photon to be emitted with an energy 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 oth[illegible]ns[illegible] first photon stimulated the emiss[illegible]n a second photon, hence th[illegible]**stimulated emission**.

How a laser works

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

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

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



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

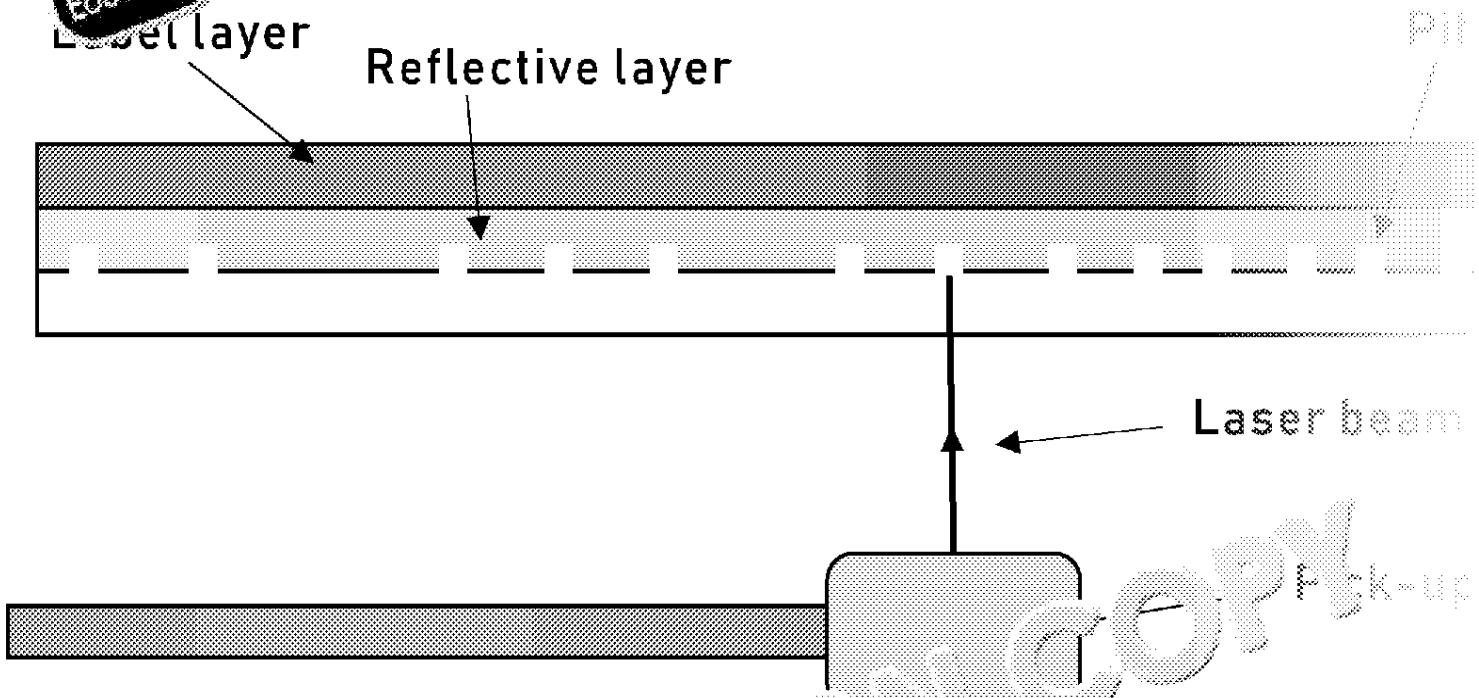
Applications of lasers

Lasers have a huge number of applications, from barcode scanners and optical [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 ver[illegible] disc
types are ordered in increasing storage capacity but are also or[illegible]n increasing

The basic optical drive is made of a **pick-up hea[illegible](PUH)** that can move along the
servomechanism. Information is stored on the [illegible] a series of 'pits' in one line
The PUH usually contains a semi[illegible] a lens for focusing the laser light
detect the reflected ligh[illegible] di[illegible]. The lens also has a servomechanism to adj
laser light is focus[illegible]ma[illegible]ot on the disc.



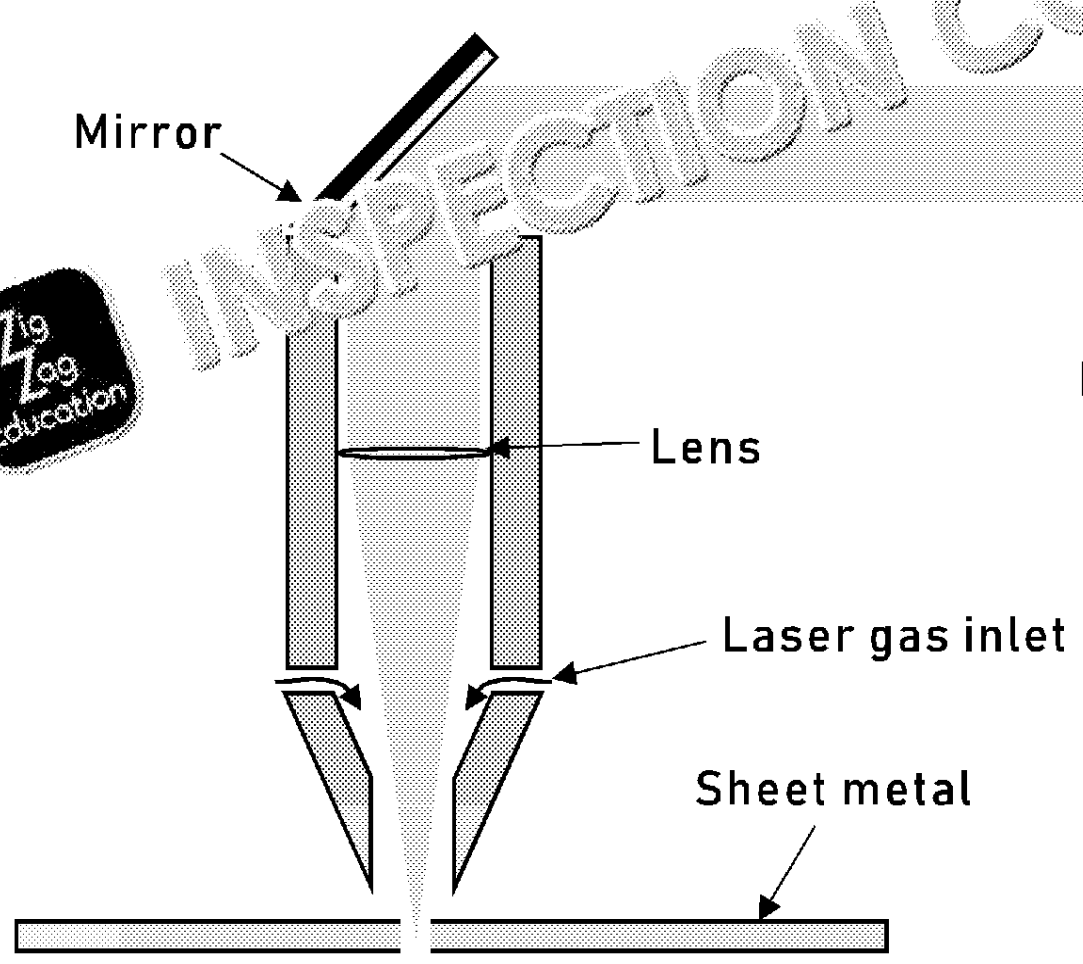
Discs can come in variations of read-[illegible]or[illegible]e (write once) and rewritable (
the read-only disc (ROM) wh[illegible]omes [illegible]pre-written data, such as a music CD.

The data is sto[illegible]es 'pits' and 'raises' in a reflective layer, similar to 1s an
Th[illegible]h o[illegible]around 1/5 the wavelength of the laser light used. This me
[illegible]ly interferes with the incoming laser light. The reduction in amplitude of
t[illegible]iodes, 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
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 cut into the
cleanly and smoothly cuts the metal in comparison to conventi[illegible] cutting method



The most common laser type used in laser cutting is the C[illegible]er, which uses CO
emits infrared light with a wavelength of about 1 [illegible]m. The emitted beam has a diam
reflected off mirrors towards the sheet metal, passing through a lens. The lens focu
point, increasing the intensity of the beam. This also allows a small amount of m
the process efficient compared to conventional cutting techniques.

During cutting, the part being cut, a gas is injected around the point of cutting b
used for mild steel, which is cut using an oxygen-fuelled burning process.
For materials like 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 [illegible]ker to re
discs to store information, discuss the future of optical disc drives and hard discs.

Extension

Lasers come in a variety of p[illegible]erating. Powerful lasers can be dangerous, especi
someone's eye. For this reason, each laser is categorised into a class; the higher the
around that laser. Research the laser safety standards and present your findings as a

Optical Fibres

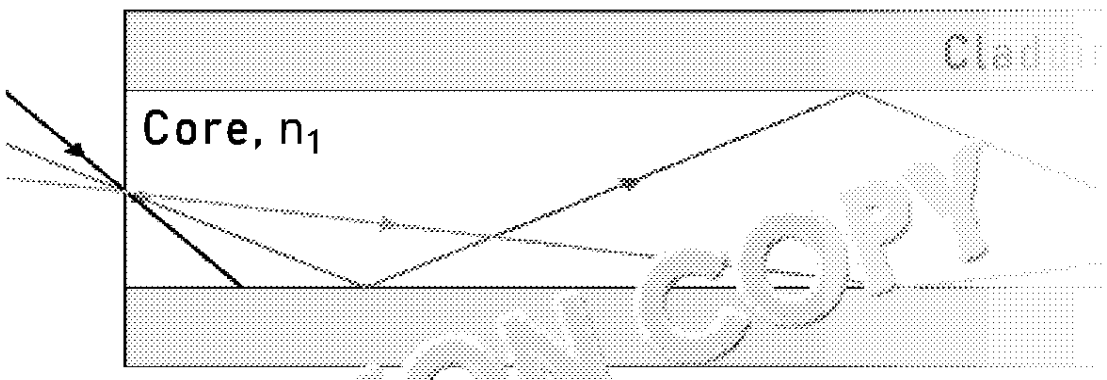
Topic 5: Waves and the particle nature of light

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

Optical fibres are a type of waveguide that transmit light in a controlled manner over long distances, modulating light signals resulting in fast (at light speed) data connections between

How they work

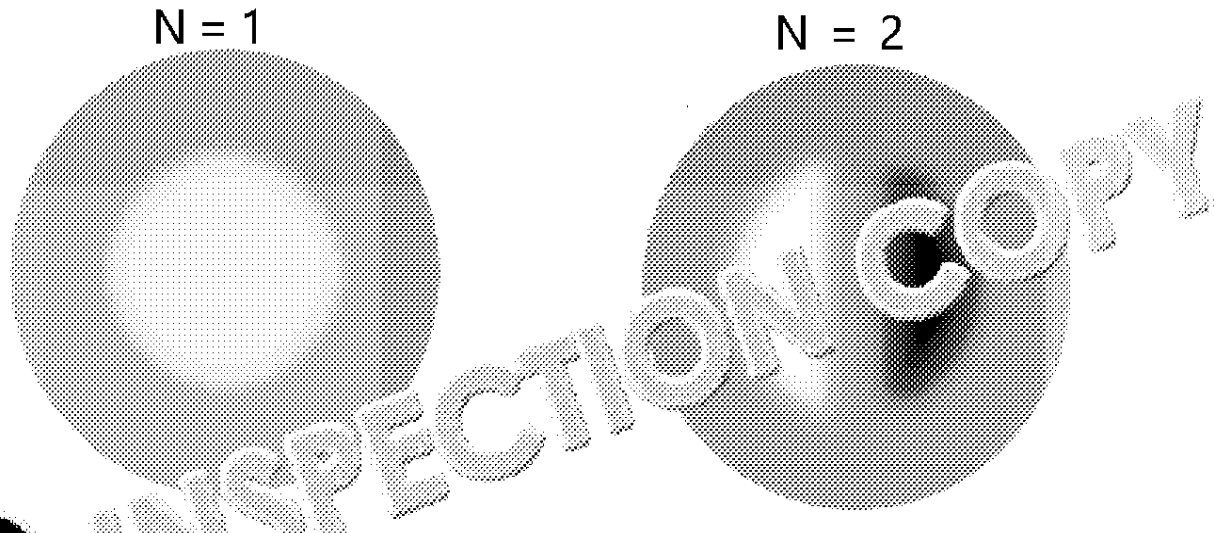
The basic fibre is constructed with a core encased in a cladding. The core has a higher refractive index than the cladding ($n_1 > n_2$), so a light ray that is incident at the boundary between the two materials at greater than the critical angle will be totally reflected. This principle is called total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



A waveguide will have a number of modes depending on its dimensions and refractive index. A mode is an electromagnetic field that propagates through the waveguide without changing shape. A waveguide can be constructed with different amounts of the waveguide's modes supported. The principle comes from maths where you can expand trigonometric functions such as

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

In this analogy, the powers of x are the different modes and the coefficients in front of each mode has to the overall function ($\sin x$). The first three modes ($N = 1,2,3$) for a circular waveguide are shown below:



White and black represent positive and negative amplitudes of the waveguide. The number of modes a waveguide can hold is finite, typically only a few. A waveguide can also be designed so that only the fundamental mode ($N = 1$) can propagate through it with all others being absorbed. This 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
travels at the same speed through a vacuum, different wavelengths trav[illegible] differen
even for a single wavelength in a medium, depending on the ar[illegible]gl[illegible] passes
have a shorter path length, meaning it will travel a differe[illegible]ds enc[illegible]d take more
at the same speed.

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

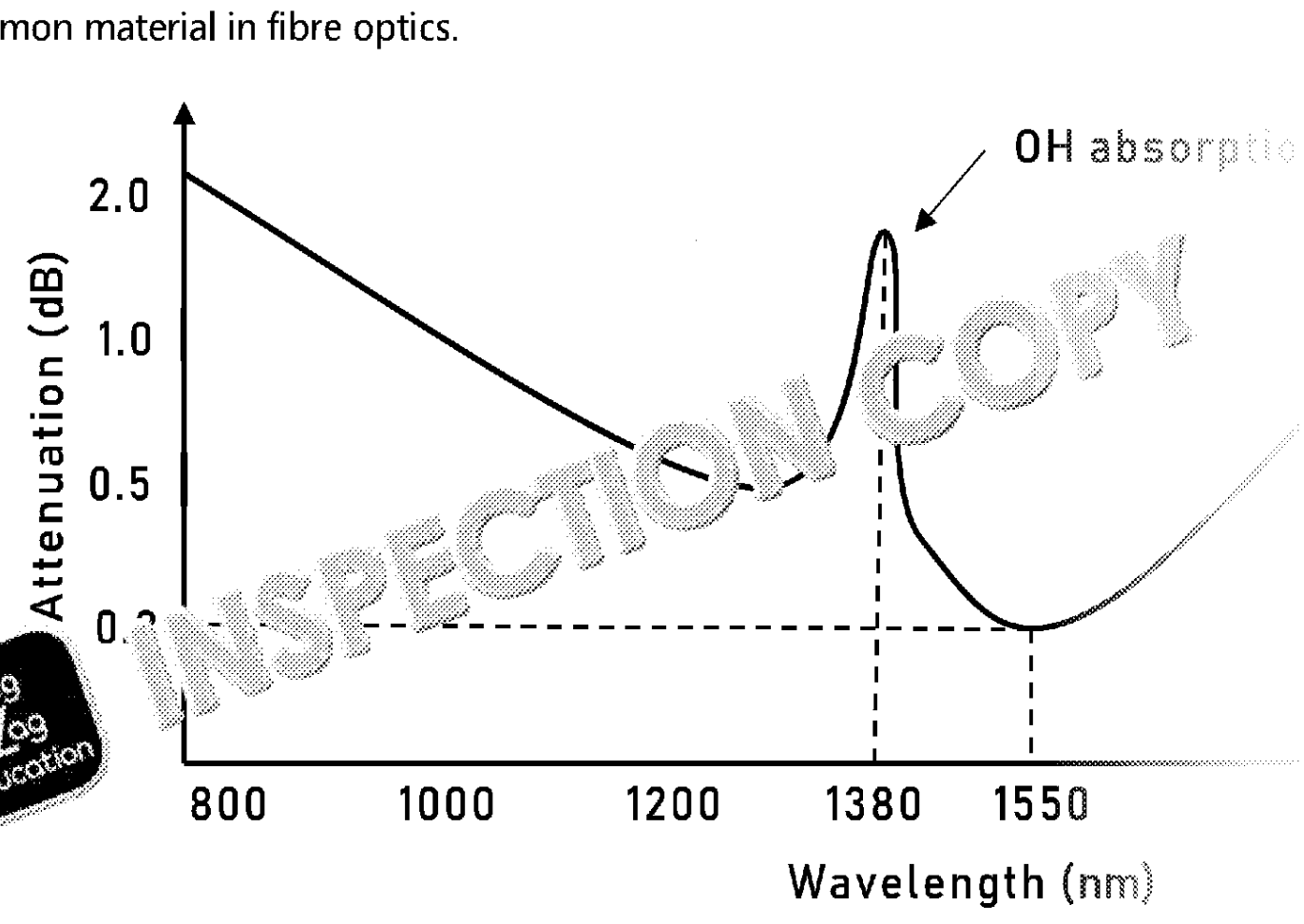
1. **[illegible]rm[illegible] [illegible]sion**: Different modes in a multi-mode fibre have differen
[illegible]e fib[illegible] were invented to remove this type of dispersion. Single-mode fib
[illegible]er, so the cheaper multi-mode fibres are used for short-distance transm
2. **[illegible]romatic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

   A pulse of light will have a range of frequencies when generated, meaning the
propagation. For a high density of information, as in today's sig[illegible]smissio
which becomes a problem. A regenerator is positione[illegible]at [illegible]0–[illegible]m in[illegible]ervals a
signal and remove this chromatic dispersive eff[illegible]t. [illegible]so, u[illegible]laser light (cohe
frequency) reduces the effect of this di[illegible]
3. **Polarisation mode dispersi[illegible]** [illegible]t p[illegible]larisations of modes can also trave
the light before it ente[illegible] fibre [illegible]emove this effect.

A[illegible]u[illegible]

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

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



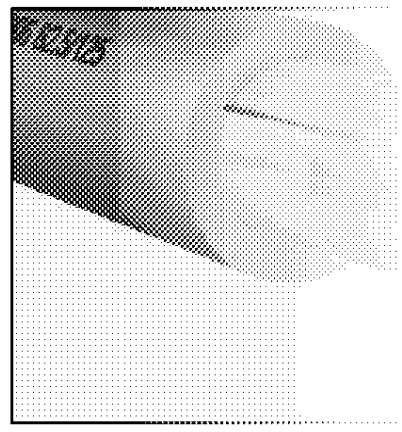
From the attenuation spectrum of silica it can be seen that the wavelengths of 1550 the spectrum) experience the lowest attenuation, which is why this wavelength is us communications. The peak at 1380 nm is caused by O–H bonds (oxygen and hydro This impurity is mainly water, which is why fibre-optic 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 is then able to with its environment.

The most common fault in TATs is a break in the cable, usually due to an anchor from a boat dragging and cutting the cable. To reduce the risk of this happening, cables are buried and have layers and layers of shielding, as seen in the cross section of a TAT above.

Endoscopes

As an optical 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 neurone cells in the nervous system (including the brain) that transmit signal as electrical impulses. By manually stimulating synapses with fibres for diseases like motor neurone disease can be researched and treated. Optical fibres that use infrared radiation for stimulation have the advantage of sending a precise impulse at the synapse with physical contact (no inflammation from injury, etc.); however, it can result in 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 sl
currently performed by TATs. Discuss the advantages and disadvantages of
ation 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.

Meta-magic

Topic 5: Waves and the particle nature of light

Keywords

Material	The type of matter which a[illegible] objects [illegible]de from
Black body	An object that ab[illegible]s a[illegible] [illegible]t radiation on it.
Refractive index	The meas[illegible] 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]ect[illegible]m, and Realistically, it will be many decades before commercial a[illegible]plica[illegible]on [illegible]t can bend [illegible] That doesn't mean metamaterials should be ignored until [illegible]esearch gets to this [illegible] are many revolutionary applications of [illegible]t ma[illegible]ls.

Radiative [illegible]

[illegible]rem[illegible]pe[illegible]that the Earth and its atmosphere act approximately like a black [illegible]sorbs radiation from space, mainly from the Sun, and emits radiation ba[illegible] i[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] infrared radiation being emitted into space. The temperature of space is just above[illegible] temperature of the Earth's atmosphere and surface is about 300 K. So when the Su[illegible] there is a large temperature gradient from the ground out into space. Objects at a[illegible] radiation with wavelengths in the range 8–13 μm, which happen[illegible] to be wavelengt[illegible] atmosphere barely interacts with. Therefore, any radiation emitted upwards by a bo[illegible] escape into space. The coolness of space can therefore be used to cool objects be[illegible]

This principle was used by the Persians to make ice in the desert. They would fill sh[illegible] the end of the day. The [illegible]ures in the desert drop rapidly at night, but not be[illegible] pool would radiate (mostly infrared radiation) that would escape up into the sky an[illegible] the shallow surface area that could radiate heat was larger, improving the [illegible]rature of the water to drop below 0 °C causing it to freeze. The Persians [illegible] rise 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 [illegible] overwhelms the emitted radiation from objects, causing their temperature to increa[illegible]

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 wavelengths to pass thro this material, any incident radiation from the Sun will be reflected away, but the infr object due to its temperature can pass through the material and escape into space.

This is very unintuitive because an object coated in this m[illegible] will cool down whe (with no direct line of sight to space) and put out[illegible] the Sun. Theoretically, this m the temperature of an object to 40 °C b[illegible]its surrounding temperature, although 5 °C below ambient temperature [illegible]ched.

One such applicat[illegible] Raman Lab's metamaterial is a filter on cooling panels. The as[illegible] an air-conditioning system. Water flows from the air-conditioning unit en[illegible] on the roof of the building. The water then cools in these panels and flo[illegible]eld trials have shown this increases the efficiency of the cooling system by

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 panel antenna. They have no mechanical parts, instead using a combination of electronics and software to control the direction of the signal. One such flat panel antenna developed by Kymeta also uses metamaterials to further improve the function of the flat antenna. The antenna's surface is covered in elements, each able to refract light in a certain direction. The refractive index (see right). The individual elements can be turned on and off in such a way as to track the satellite as it moves across the sky, even though the antenna is not actually moving. These antennas are much more efficient than standard antennas because compared to satellite dishes, making them useful for mobile applications such as planes.

Comprehension questions

1. What is the definition of a metamaterial?
2. What wavelength range do objects at 300 K mostly emit electromagnetic radiation?
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 come up with as many applications of Raman Lab's metamaterial as you can. Industry/areas could include transportation, civil engineering

Extension

Research how metamaterials that bend light around an object, i.e. make it invisible to certain wavelengths, work and if the Harry Potter cloak of invisibility is a possibility in the future. Present as a two-minute presentation.

Imaging the Invisible

Topic 5: Waves and the particle nature of light

Keywords

Photon	An elementary particle that is a quantum excitation of the electr
Focal length	The distance betwe[illegible] lens [illegible]bolic mirror and its point of
Wave function	The property [illegible] particle that describes its position wi

Light is made [illegible] oscillations in the electromagnetic field called photons. These p[illegible] macroscopic effects such as absorption, transmission and reflection.

When light is reflected off an object and enters our eye, our brain then determines t[illegible] 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 [illegible] energy of incident photons, or the object is much smaller than the wavelength of th[illegible] interactions are very rare. So how do we image things which don't interact with ligh[illegible]

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 material 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.

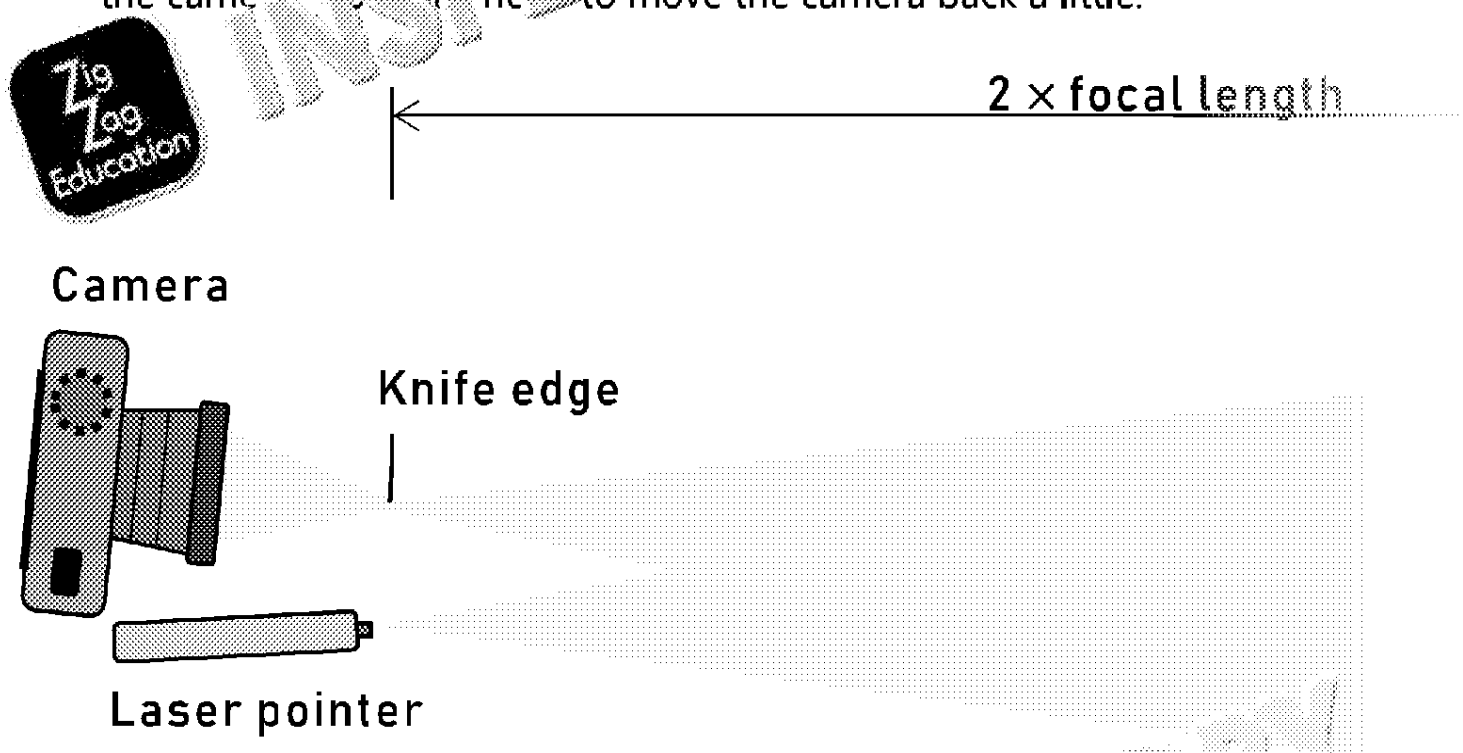
The density of air is not constant. It can vary due to turbulences such as the wind, or due to pressure changes, like sound. In 1864, August Toepler, a German physicist, was [illegible] supersonic motion (faster than the speed of sound). The resulting motion [illegible] dense pressure waves in the air.

To see these pressure waves, August Toepler developed an imaging technique calle[illegible] ('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[illegible]

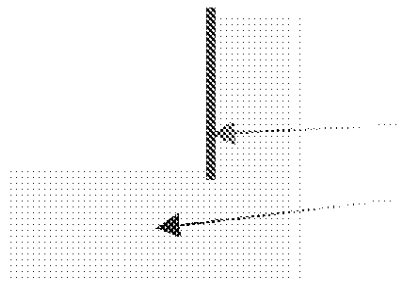
How does it work?

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

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



- The point source of light is reflected by the parabolic mirror and is focused back to the source.
- Angle the mirror slightly so this focused light instead just misses the source and the 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 light to be refracted. Therefore, some densities of air, say low density, will be blocked by the knife / by the filter and will not pass through. This gives our final image some contrast so we see the different densities.

A small point source of light is used, so any change in direction of the light, due to slight variations in air density, will cause the focused light to miss the normal focal point and create an image in the camera showing the slight variations in air density as light and dark contrast by the knife edge.

Schlieren photography is used a lot in aerospace and aeronautical engineering. Combining the behaviour observed in wind tunnels, and designing models, build a picture of how aerodynamic photography is not unique to variations in air density, however; it can be used to image changes as the temperature diffuses through a tank of water (remember the hotter a fluid is, the less dense it 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 of the atom two methods that are used in scanning tunnelling microscopy (STM) and atomic for

Scanning tunnelling microscopy (STM)

Scanning tunnelling microscope (STM) take advantage of quantum tunnelling. Th a particle to tunnel through a potential energy barrier because its wave function ap

The wave function of a particle is a quantum description of the particle and is relate a particular position. The probability of finding a particle far away from t bility of a particle tunnelling through a potential barrier is small, but it isn't

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 the to the surface (or vice versa), constant.

The tunnelling current is directly proportional to the distance between the tip and surface, so if the surface has a bump in it the tip will raise and lower over the bump. This movement of the tip is recorded by the computer and eventually enough data is collected to generate an image of the topology of the surface.

The image is the image of a molecular structure shown on the right. To give you a the number of measurements an STM makes, if the STM were the size of the Eiffel tower variations in height due to the 'bumps' of each atom would be around 2 cm!

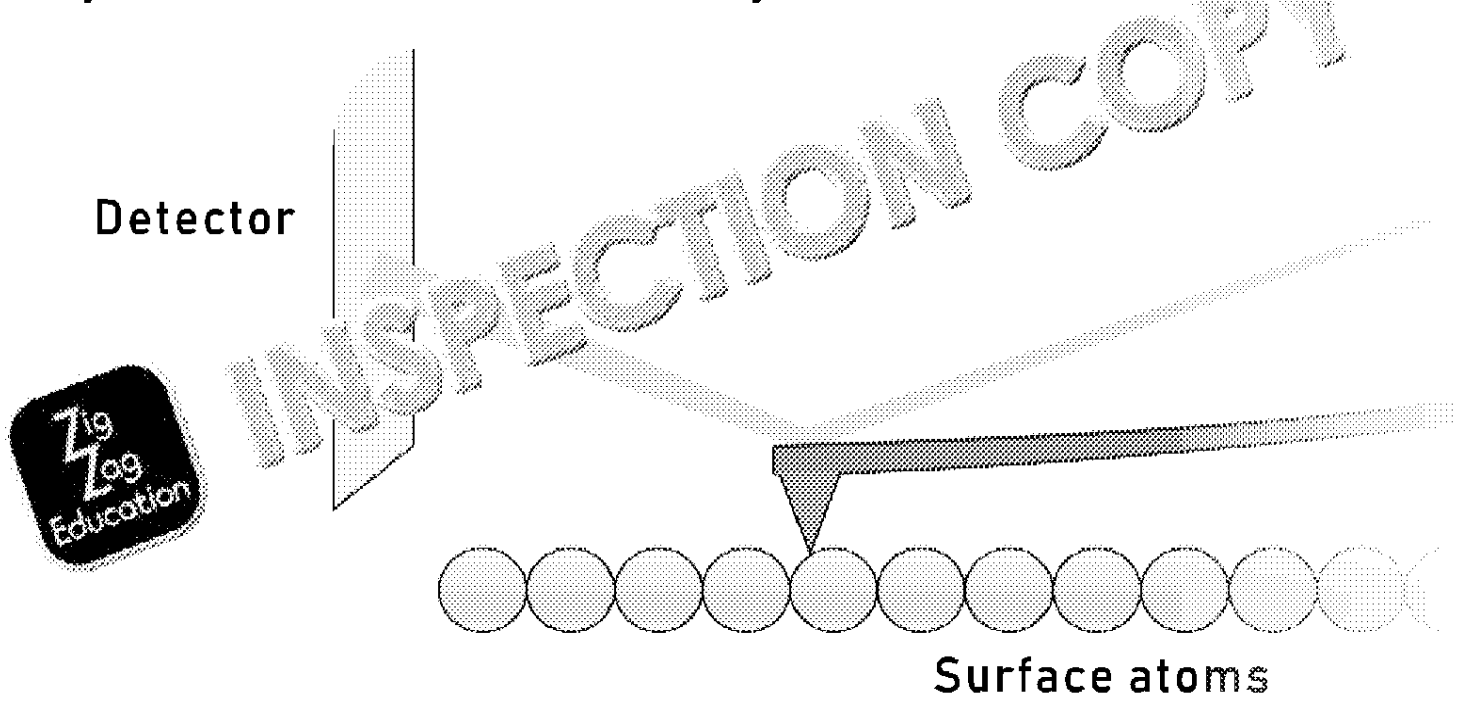
STMs can also be used to manipulate atoms. By allowing the tunnelling current to to a particular atom, the tunnelling current increases. This results in an attractive for tip which allows the tip to drag and position the atom anywhere on the surface. IBM this technique called 'A Boy and His Atom' (**https://www.youtube.com/watch?v=oSCX78-8-q0**).

Atomic force microscopy (AFM)

The disadvantage of STMs is that the surface must be able to conduct electricity, or complete and no potential difference between the surface and tip is set up. Atomic however, can also image the surface of insulating materials.

An AFM uses a technique that is very sensitive to variations in the movement of a t surface. The tip in this case moves up and down purely due to the electrostatic repu the microscopic version of what we perceive as touch. To measure such tiny variations

The tip used is a cantilever, a spring-like object that will experience a restoring force 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 beam away from the surface and cantilever so any small variation in the cantilever's ampli



The difficulty with AFM is the number of sources of forces that can act on the cantil 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 or repulsion du tip and surface.
- **Chemical forces**. These are caused by the covalent or ionic bonds between at These forces tend to be short range compared to the others.
- **Capillary forces.** A liquid layer on the surface (or condensation in the air) will surface, creating a sort of attraction between the two. The meniscus (the bounda result in strong forces that dominate all other forces. To get around this, the A in water so that no 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 a surface.

Extension

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

- electron microscopy
- medical imaging with ultrasound

Topic 5: Waves and the particle nature of light

Keywords

Black body	A body or object that absorbs all incident radiation
Photons	Quantised packets of electromagnetic radiation
Wave function	The description of the 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 (i.e. allows for a system to have any value of energy), that time progresses at a constant rate, and that the 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 of 37 °C and 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 for long wavelengths, but broke down at short wavelengths (high energy, high temperatures). Wien's law was used to describe the emitted radiation for short wavelengths, but deviated from experimental results for long wavelengths. Therefore, there was a need for these two models to be combined into one.

Max Planck proposed a new law that could explain the experimentally observed radiation for all temperatures and wavelengths. 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:

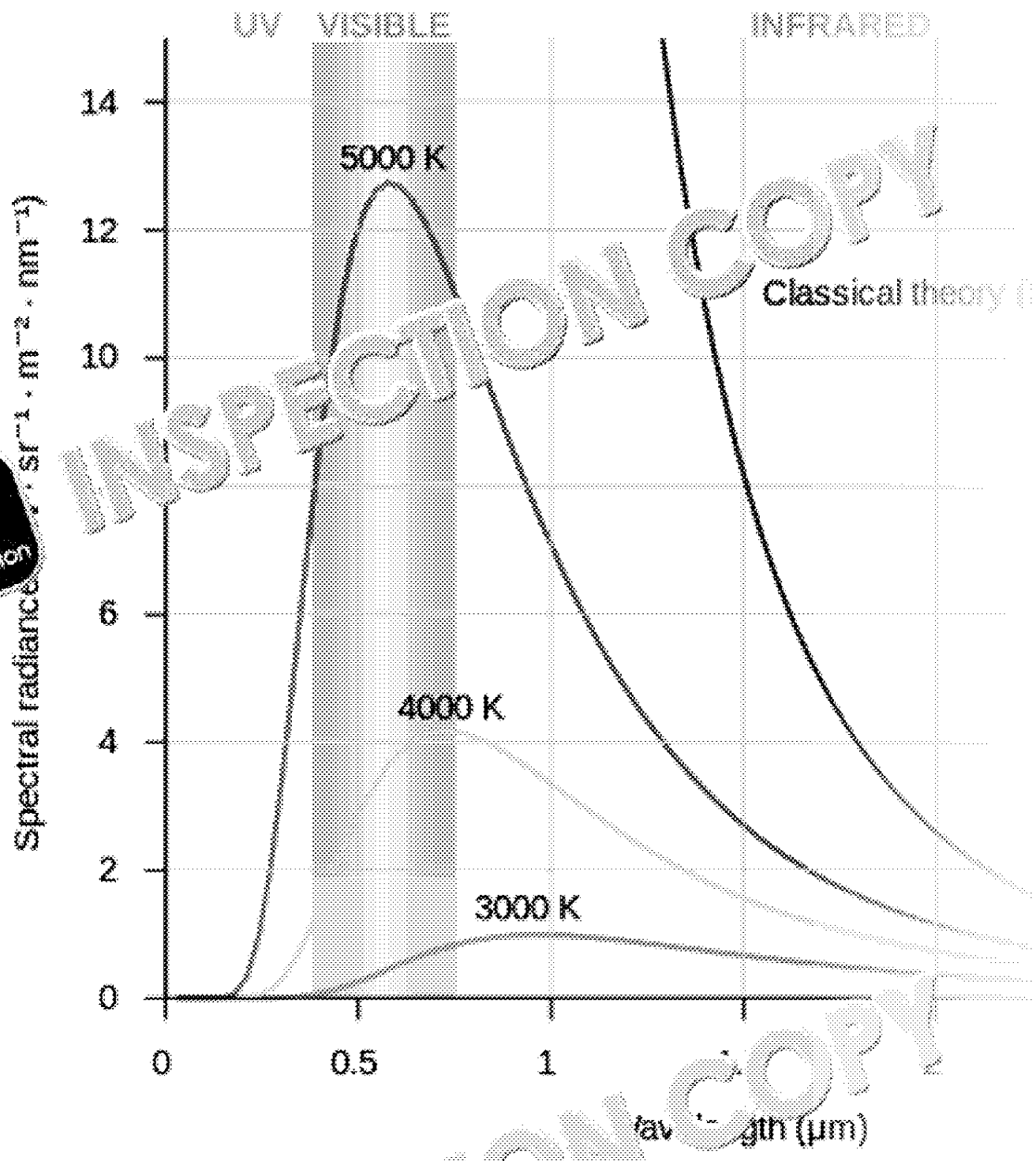
$$\lambda_x = \frac{2L}{n_x}$$

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[illegible] for different temperatures, as well as the Rayle[illegible] theory plotted for 5000 K. The peak for temperatures of around 5000 K is in t[illegible] visible spectrum.

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

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

Think of the circumference of each electron orbit. Similar to the standing waves in Planck's derivation, each electron orbit 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 [illegible] wave-particle duality. Hypothesised by Louis de Broglie, waves, such as light, can [illegible]n) and particles, such as electrons, can act like waves (so diffract, refract [illegible] b[illegible] 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[illegible] a specific place. Erwin Schrödinger developed an equation that modelled how a wa[illegible]

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

Did you know?

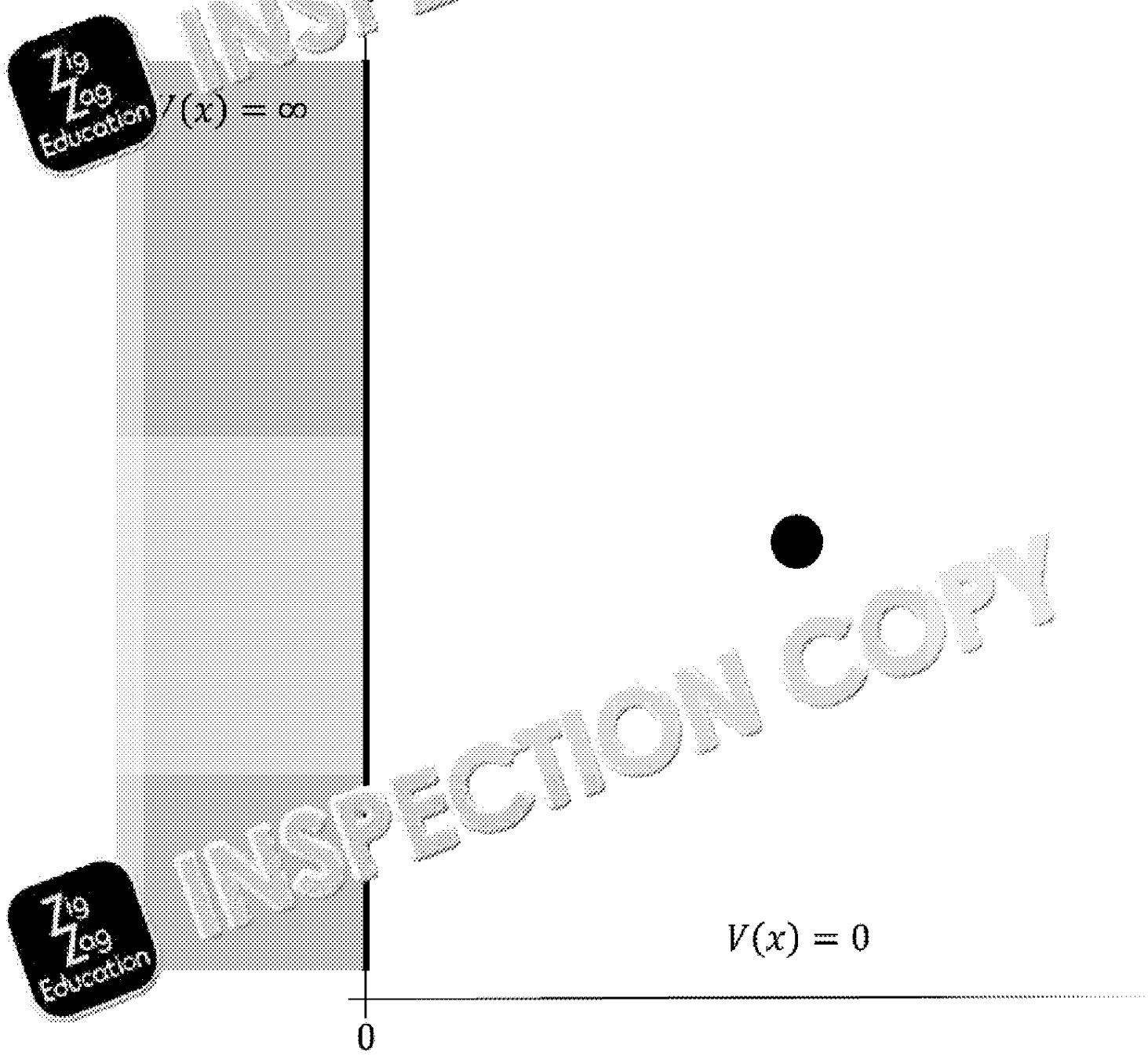
Max Planck was awarded the Nobel Prize in 1918 for his derivation that led to the discovery of photons, Albert **Einstein** was awarded the Nobel Prize in **1921** for his work on the photoelectric effect, **Niels Bohr** was awarded the Nobel Prize in **1922** for his work on quantised orbitals in atoms, 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 or

A particle is trapped in an infinite well, that is, it's trapped betwee[n] tw[o] v[al]l[s] of infi[nite] escape. Outside the well, there is a barrier of potential en[ergy] (V([∞], and insid[e] of V(x) = 0.

The position of the particle can b[e] [de]fi[ned] by 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[d] function of a particle is a description of the particle in space and time, giving the pr[obability] in a particular location at a particular point in time.

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

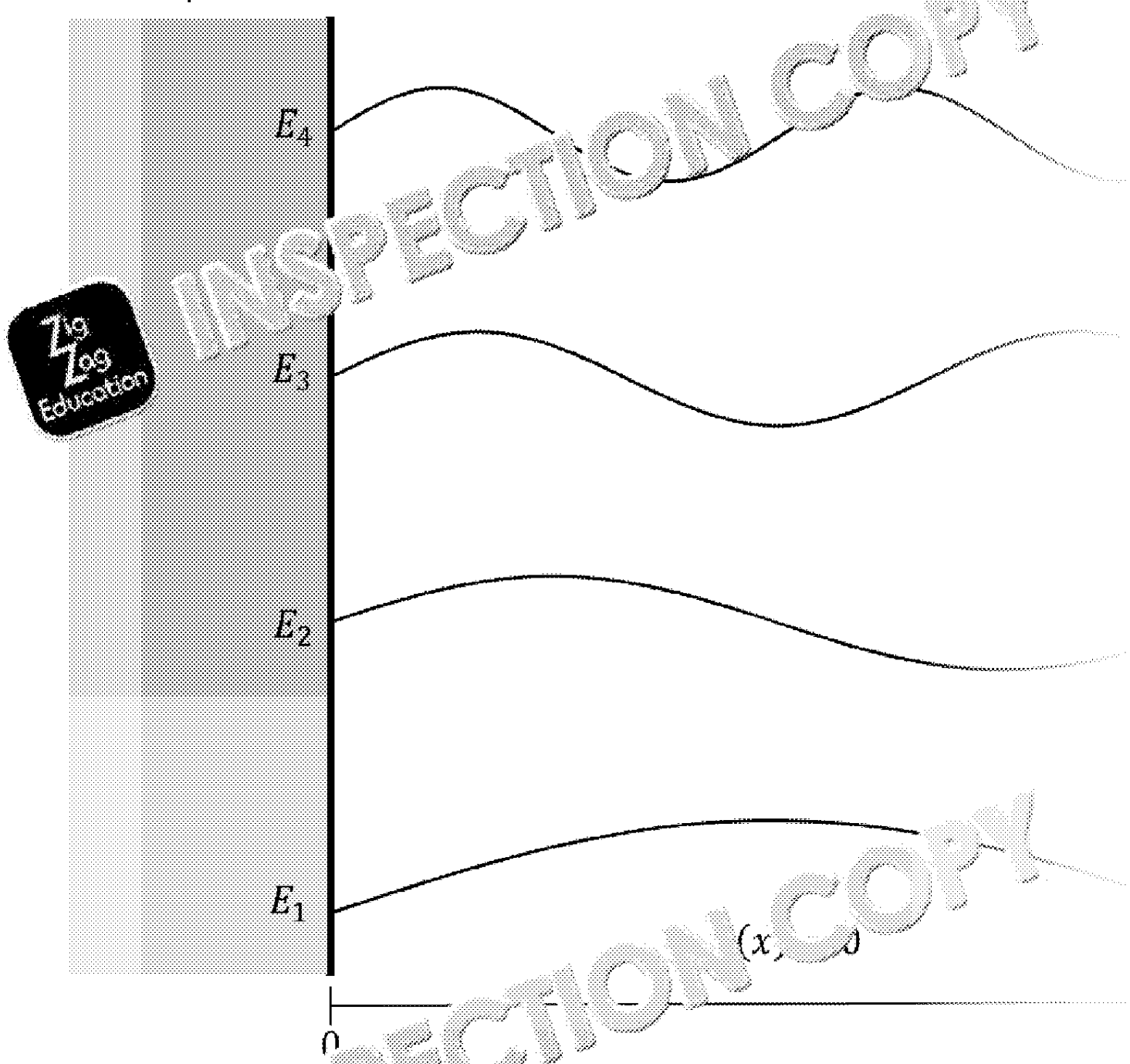
$$\psi_n(x) = \sqrt{\frac{2}{\quad}}\sin\left(\frac{n\pi}{\quad}\right)$$

where n is an integer (representi[ng] [the] [n]th discrete possible solutions). You m[ay] solution of the electromagnetic radiation modes in the derivation of Planck's law. Th[ese] states crop up oft[en] [in] quantum mechanics. It's also possible to derive the energy [of] fu[nction]

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

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 stat
the particle, given by the energy equation above. The particle cannot exist within t
have one of the quantised energies from this equation. Below is a plot of the first f
in an infinite potential well.



For e[illegible] sta[illegible] 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 poten
what is the probability of finding the electron in the centre 2 pm of the well?

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

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

$$p(4 < x < 6) = 3[illegible]$$

So there is a 39 % chance of finding the partic[illegible] tw[illegible]n [illegible] and $x = 6$, [illegible]
how this probability doesn't depend o[illegible]e [illegible] the electron, only its ener
dimensions. The energy of th[illegible] 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 functions, and, therefore, energy levels that can exist. This is why Niels Bohr suggested have discrete energies, which led to his Nobel Prize.

The predictions from the Schrödinger equation and other quantum mechanical theories 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 function Bohr, Heisenberg and others tried to answer these questions. Their description is known interpretation.

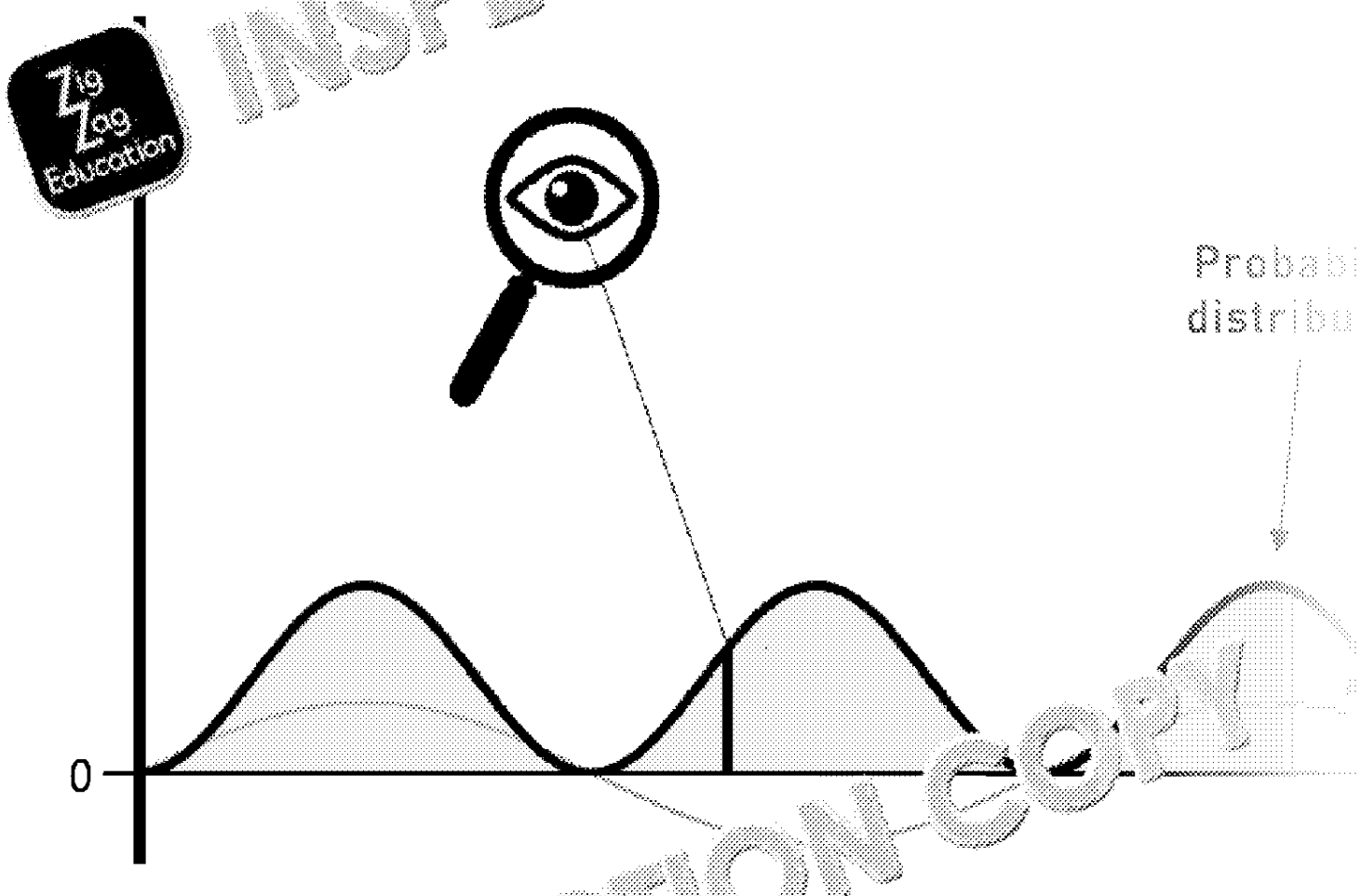
Copenhagen interpretation

Developed 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 probabilities are one number, like the probability of getting heads in a coin flip. A probability distribution is a graph that represents all the values a system can take and the probability of each (in the case of our particle in a box, the values are positions along 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.

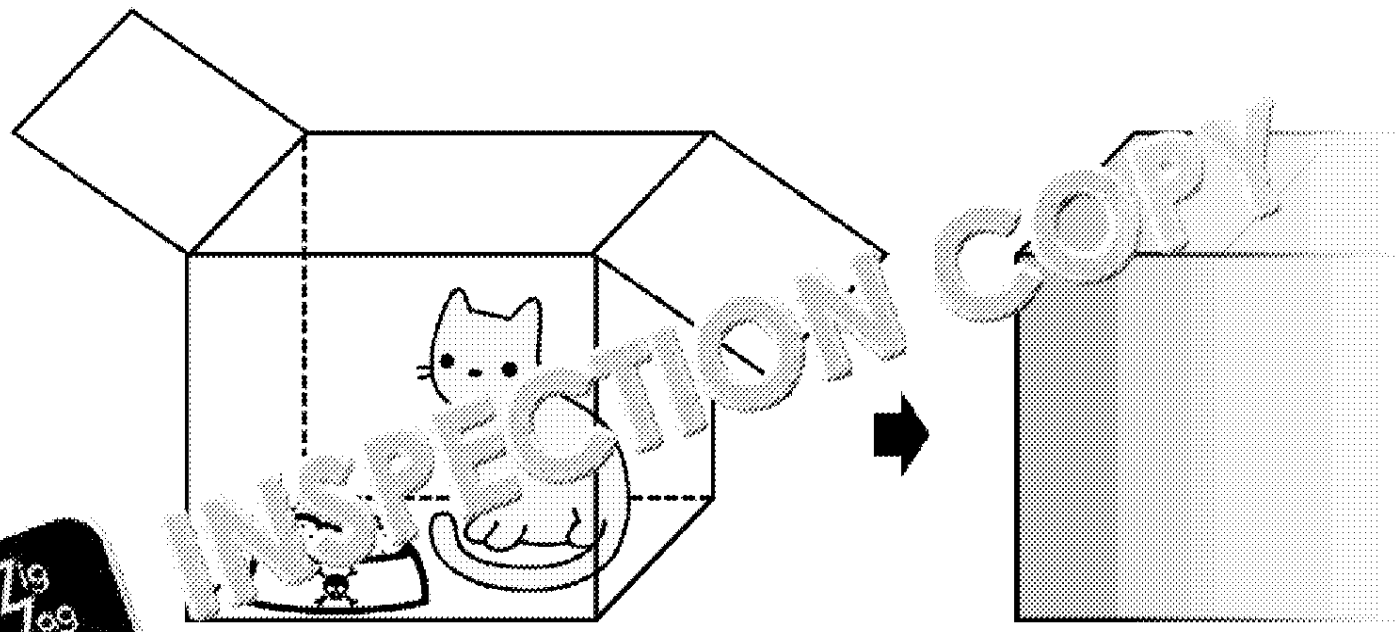
Each state has an associated probability calculated from its wave function. Below is the function, $\psi_3(x)$ and its associated probability distribution for our particle in an infinite well has this wave function when its energy is measured. When the system is influenced by an external measurement,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



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

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

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 fate wave function. It is only when the box is opened that the state of the cat is determi 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 (hopefully) living cat, what has happened the possibility of a dead cat been a? Or is there a parallel universe where the more gruesome sight? Or, does every collapsing wave function of every atom, ele universe or universe with 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 observe quant suggest that quantum mechanics is wrong, or that there's something incomplete

Extension

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

Mark Scheme

Article	Question	
Big Engineering: The International Space Station	**1**	6. Salyut 2 failed duri[illegible] aun[illegible]
	2	It was an inter[illegible]ion[illegible] m[illegible]vent because th[illegible] debris [illegible] [illegible]opulated areas.
	3	[illegible] [illegible]al section, USOS, and the Russian [illegible]
		[illegible] two from: • Bones become less dense. • Humans 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 i[illegible] send humans. • It gives us access to planets/asteroids with[illegible] such as metals that are rare here on Earth. • By sending humans into space we reduce t[illegible] extinct (due to global disasters, etc.). • Research could help understand[illegible] d[illegible] devel[illegible] potentially saving lives [illegible] Ea[illegible]. • The increase in f[illegible]dam[illegible] for[illegible] research [illegible] expands the spa[illegible] industry.
It's Not Exactly Rocket Science	**1**	$T = (v + v_p)\left(\frac{dp}{dt}\right.$ $T = (0 + 1200)(75$ $T = 9 \times 10^{6}$ N
	2	Any one from: • $\boldsymbol{AC + BC = constant}$ where $\boldsymbol{A}$ and $\boldsymbol{B}$ are t[illegible] ellipse • The distance between the centre of the ell[illegible] to $\boldsymbol{e \times a}$, where $\boldsymbol{e}$ is the eccentricity of the [illegible]
	3	Periapsis and apoapsis respectively
	4	$\boldsymbol{v} = \sqrt{GM\left(\frac{2}{r} - \frac{1}{a}\right.}$ $v = \sqrt{G(1.99 \times 10^{30})\left(\frac{2}{(2.06 \times 10^{4}}\right.}$ $v = 2.66 \times 10^{4}$ m[illegible]
	Discussion	Points that could be discussed: • More efficient rockets [illegible] ba[illegible] busin[illegible] space cheaper. • A quicke[illegible] [illegible]ar[illegible] [illegible] of rockets makes mo[illegible] [illegible]om[illegible] [illegible] a more regular, leading to m[illegible] • C[illegible]mpetition in the space industry drives [illegible] developed. • Advertisements in space or on a mission t[illegible] or importance that space or the mission h[illegible] • Expanding the space industry to many pri[illegible] universal standards being lost, although th[illegible]

Article	Question	Answer
Special Effects	**1**	Galilean relativity (all non-accelerating refere Maxwell's equations (giving a fixed valu time slows down and speeds up always travels at c thro
	2	$t' = \frac{t}{\sqrt{1-\frac{v^2}{c^2}}}$ $t = t'\sqrt{1-\frac{v^2}{c^2}} = 880 \times 10^{-9} \times$ $t = 536$ ns
	3	For the observer, the time it takes for the muon because of time dilation, and for the muon only For the muon, the Earth is travelling at relativi covers through the atmosphere is contracted whole atmosphere in its lifetime.
	Discussion	Points that could be discussed: • particle accelerators • medical imaging • mass spectrometry • GPS • high-precision equipment where even a sm timing can have a big effect
Energy Storage	**1**	Thermal energy storage in media such as wate
	2	$I = \frac{1}{2}mr^2$ $= 13.1 \times 0.25^2$ $= 0.844$ kg m^2 $E = \frac{1}{2}I\omega^2$ $E = \frac{1}{2} \times 0.844 \times 2$ $E = 3.4 \times 10^3$ J
	3	The flywheel stores and releases the generated spreading the power out during each cycle. Thi output of the engine smoother and easier to h
	4	DRAM uses a refresher circuit to keep the stor 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 pumpe • 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 sufficient argued

Article	Question	Answer
Fluid Dynamics: Going with the Flow	**1**	The continuity equation, three Navier–Stokes e equation.
	2	$\frac{1}{2}\rho v_0 l_0$ / η
	3	$F_D = \frac{1}{2}\rho v^2 A C_D$ $F_D = \frac{1}{2} \times (2.46 \times 10^{-2}) \times 1000$ $F_D = 5.7 \times 10^{4}$ N
	4	The foil splits the incoming air into two parts: the foil, the other travels underneath. These pa of the foil at the same time. The top of the foil so the air travelling over the top must travel fa 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 t just b • The information learnt from studying chaot areas/industries. • The computational power needed to resea ... possible application for powerful computer ... computers and future technologies.
Interferometers: Getting into ... positi...		Initially the beams are in phase because they c coherent light source. The beams then travel wi 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 length of each beam will result in a phase diffe allowing the change in path length to be meas...
	2	The aim was to measure the difference in speed arms of an interferometer. The interferometer w 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 betwe speed of light constant.
	4	They were each approximately 30 solar masses
	Discussion	Points that could be discussed: ... further research into black holes could be p ... escape black holes, making them invisible t ... There could be better research into neutro behaviour. • Dark matter is only known to interact with t gravitational waves will give us insight into • It could be a new method to back up and c electromagnetic telescopes.

Article	Question	Answer
Earthquakes: Shaking Things Up	**1**	e.g. the San Andreas fault line
	2	$E > 10^{\frac{3}{2}} \times 2.5 \times 10^{\ldots}$ $E = 5.\ldots \times 10^{\ldots}$ J
	3	The amplitude of the seismic waves as they are (lose their energy) as they propagate through the amplitude of a seismic wave, the further it
		The use of satellites that are sensitive to the EM 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 co 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, solving our energy
Holograms: Seeing Things That aren't There	**1**	The reference beam is used as a source of light reflected beam from the object. The holograph interference will then display an image of the identical reference beam
	2	An array of charged silicon discs that can tur computer
		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 states that informatio is stored as deformation on the surface of the information isn't lost/destroyed, which satisfies mechanics.
	Discussion	Points that could be discussed: • Where is this 2D surface where all informa • Why would the universe be a hologram? • What is the physical meaning of a hologra • A holographic image is projected from a 2D information of our universe is stored on a space which our holographic universe is pr • Could there be new unified physics based • How is the information stored on the 2D s hologram that is the equivalent of the re
Laser Focus	**1**	A gain medium has more excited atoms than at photon with the right energy will cause an elec to its ground state, emitting another photon. T emission. These photons will cause more photo stimulated emission, resulting in a chain reactio gain medium ensure generated photons pass t The result is the amplification of light in the ga
	2	5:1

Article	Question	Answer
Laser Focus	**3**	Either oxygen is used to help burn the material cutter, or nitrogen is used to push the excess m be disposed of.
	Discussion	Points that could be discussed • SSDs will replace optical discs for information repl • Sales of CDs, DVDs and Blu-ray will diminish w elessly downloaded. • Storage of 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 mec • A disadvantage of using cloud services ove having so much information stored in one p
Optical fibres	**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 re type of dispersion. Single-mo ver, so the cheaper multi-mode fibre ansmission. 2. **Chromatic dispersion**: Different frequenci colours, although this also applies to EM r part of the spectrum) travel at different spe can be sub-divided into two other types of • Material dispersion: The refractive ind depending on the frequency of light t • Waveguide dispersion: The way the m 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 p of information, as in to signal tra to overlap, which becomes a problem at 60–70 k int along a fibre to his chromatic dispersive effe ferent light with the same frequen dispersion. 3. **Polarisation mode dispersion**: Different po travel at 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 and[illegible] • can constantly chan[illegible]ge me[illegible]s of connect[illegible] Disadvantages: • diffi[illegible]ostly to install and maintain[illegible] [illegible]e to damage from radiation and objec[illegible]
Meta-magic		A [illegible] material is a material that goes beyond [illegible] normal materials. This typically means it manip[illegible] electromagnetic radiation, resulting in effects th[illegible]
	2	8–13 μm
	3	The Persians would fill a shallow bath with wat[illegible] The ambient temperatures in the dessert at nig[illegible] lack of clouds), which would cause the water to[illegible] shallow water would radiate heat into the atmo[illegible] infrared radiation emitted is barely absorbed by[illegible] water past its freezing point.
	4	A negative refractive index means the compone[illegible] parallel to the boundary is reflected, causing th[illegible] back in one direction as it passes through a bo[illegible]
	Discussion	Points that could be discussed: • coating buildings / transport vehicles in the[illegible] hot climates • use as a heat shield for Sun-gazing satellite[illegible] • keeping fresh produce from farms cool • [illegible] thermos flasks to keep drink[illegible]
Imaging the Invisible	**1**	[illegible] set-up to photograph schlieren in[illegible] apparatus 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 differences[illegible] help the engineers design aerofoils or other ob[illegible] to perform as they require.
	3	Quantum tunnelling is the effect of a quantum[illegible] moving through a potential energy barrier. This[illegible] has an associated wave function that is related[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 over the[illegible] chance of finding the particle on the other side[illegible] side, the particle has tunnelled through the bar[illegible]
	4	Capillary forces are created by a meniscus, a bo[illegible] gas (such as water and air), that creates an attra[illegible] object that it is connected to. These forces can be[illegible] the object entirely in a fluid, such as water[illegible] Therefore, the water vapour.

Article	Question	Answer
Imaging the Invisible	**Discussion**	Points that could be discussed: • Friction, surface roughness and defects co • STMs can image the conduc perties design nanostructures • STMs can manip ate atoms, so can • STM used design, build and res ico d ctors. • AFMs can analyse non-conducting objects crystals of amino acids • Imaging the nano-sized biological objects understanding and even cures for diseases
to the m 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 s 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 c
	3	The analogy describes the state of a cat that is simultaneously alive and dead. Reality when state of the cat is det ined. The analogy app interpretation o qua tum mechanics, which say mecha ca , can be in all possible states by 'en served does it fall into one state. S to point out how 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 syste 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 abo