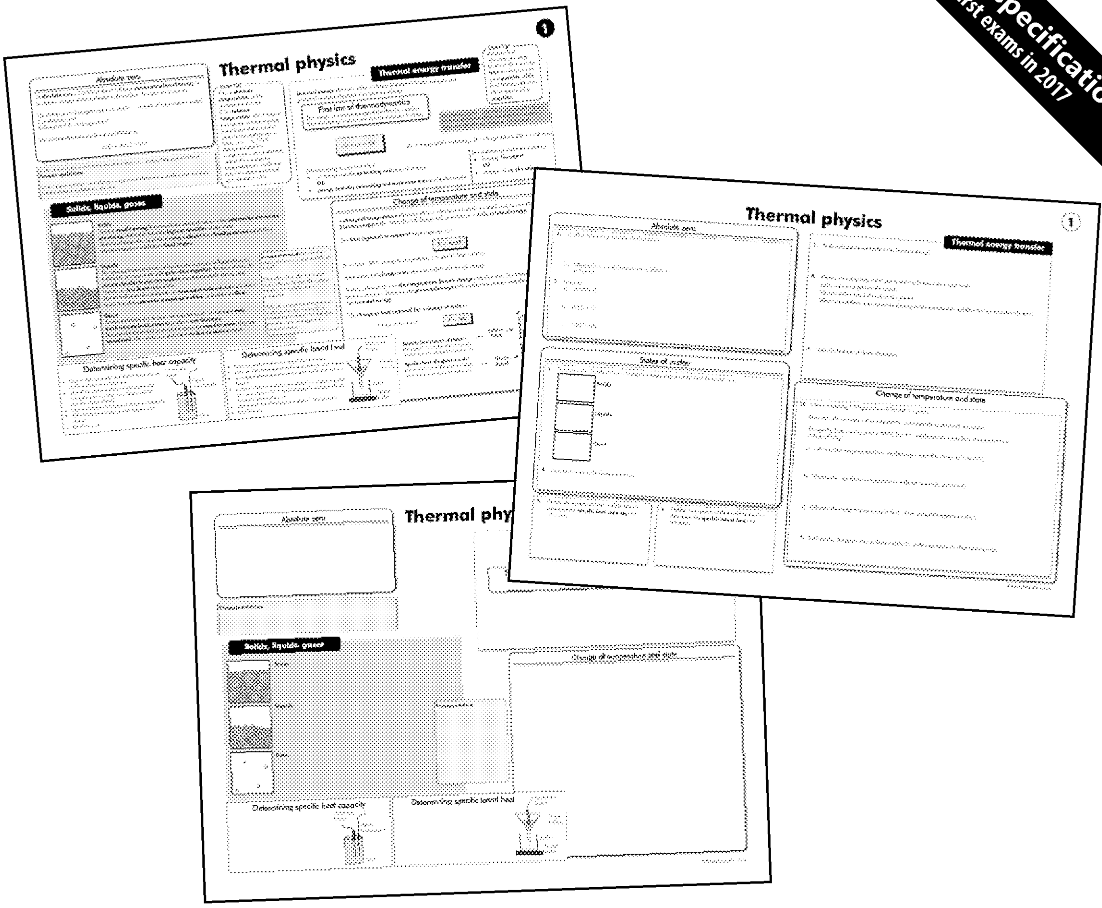
2015 specification
first exams in 2017



Topic on a Page

For A Level Year 2 OCR Physics A

zigzageducation.co.uk

POD 9283

Contents

Teacher's Introduction

This topic-on-a-page resource has been designed to help your students revise the test their knowledge after you have taught each section of the **OCR A Level Year** modules 5 and 6. Each page is closely tied to the OCR specification, ensuring all a covered. Activity pages are designed to be complementary to OCR A Level Topic Education, so students won't be repeating the same questions.

There are four sections to this resource, each with its own features:

1. **Topic-on-a-page sheets**: these are the main pages which intend to clearly consolidate and recap all the key information from Year 2 of the OCR A Physics
2. **Activity pages**: these are identical to the Topic-on-a-page sheets, but contain variety of tasks, from filling in missing words to performing calculations. The activity pages aim to ensure the student understands all the key knowledge required of them and gives them the opportunity to demonstrate how well they have remembered and understood the content of the course.
3. **Outline pages**: these are the Topic-on-a-page sheets, but with most of the content removed. Students can research the topics, e.g. for homework, and in as much information as they can.
4. **Mark scheme**: full answers for the activity pages.

The 'topic-on-a page', 'activity' and 'outline-only' sheets are designed to be A3 si at A4 with no loss of detail. When photocopying activity pages on A3, we sugges worksheet on the reverse. If using at A4 size, we suggest photocopying each A3 as a double-sided A4 page to avoid shrinking the space available for answers.

Each page presents information in a variety of ways, including:

- **Bold key words** – essential terminology in bold, allowing students to skim a
- **Bullet point processes** – complex processes and lists have been summarised
- **Graphs** – sketch graphs illustrate complex points without providing unneces
- **Comparison tables** – a quick way of comparing key features of different stru
- **Method and calculation boxes** – concisely state the equations used in requi
- **Exam tips** – aid memorisation, revision and exam technique in areas where s

We hope you find these pages useful during your teaching and your students' re

Thermal physi

Absolute zero

At **absolute zero** (-273 °C) an object will have **minimum internal energy** as the kinetic energy of the molecules will have been brought down to zero.

The Kelvin scale of temperature is an absolute scale of temperature, with 0 K at absolute zero.
A change of 1 K = a change of 1 °C.

The relationship between kelvin and Celsius is:

$$T(K) \approx \theta(°C) + 273$$

If two or more objects or systems are at the same temperature, they are said to be in **thermal equilibrium**.

If two or more systems can exchange energy or mass between each other, they will t… towards thermal equilibrium over time.

Exam Tip!
T is an **absolute temperature**, and is measured in kelvins.
θ is a **relative temperature**, which relates to a specific reference point. For Celsius, this reference point is the triple point of water at 0 °C or 273 K.
Always use absolute temperatures in calculations, unless it's a change in temperature, in which case relative temperatures will give the same value.

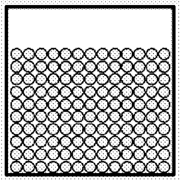
Internal energy: th…
potential energies o…

First la…
The change of in…
the total energy …

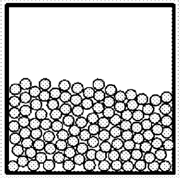
Δ…

Internal energy is c…
- **no energy tra…**
OR
- energy transfe…

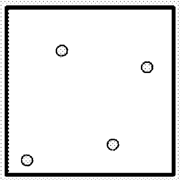
Solids, liquids, gases



Solids
There is **small spacing** between atoms and molecules, so the **intermolecular forces are strong**, and solids have the **highest densities** of any state.
Atoms and molecules in solids are **very ordered** have **fixed positions** which they vibrate around, so solids have **fixed shapes**.



Liquids
The spacing between atoms and molecules is greater in liquids than in solids, but the spaces are still **quite close together**. Because of this, the **intermolecular forces are weaker**, but still relatively strong, and liquids are **less dense** than solids.
Atoms and molecules in liquids are **somewhat ordered** and can't move much, but they **can move around each other**, so liquids can **flow**.



Gases
Atoms and molecules in gases are very far apart, so they have **very weak intermolecular forces** and have **low densities**.
Because the atoms and molecules in gases are **very far apart**, they are **unordered**. The atoms and molecules are **free to move** around.

Brownian motion describes the erratic motion of a small particle in a fluid.

The molecules in the fluid move randomly and hit into the particle, making the particle move randomly.

This can be seen in smoke particles suspended in air – rather than remaining stationary or moving in one direction, they appear to move around.

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kinet…

The h…

$m =$ …

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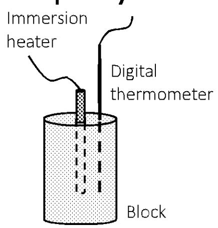
the in…

The c…

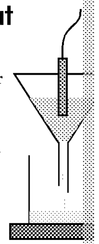
Determining specific heat capacity

- Place immersion heater and digital thermometer in block or beaker of substance
- Heat block and record the energy transferred using the power rating of the heater and the amount of time elapsed
- Measure temperature of block at regular intervals
- Plot energy transferred against temperature change
- Gradient is mc



Determining specific latent heat

- Place immersion heater in a funnel filled with ice
- Heat ice, determining energy from the power of the heater
- At regular intervals, measure the mass of the water in the beaker
- Compare mass to a control set-up, which is unheated, and the mass of the water from this beaker is subtracted from the mass of the melted ice
- Plot energy transferred against mass of melted water
- Gradient is L



Ideal gases

Ideal gas laws

Gas laws: a set of **experimental** laws that look at the relationship between pressure, volume and temperature of a gas.
Molar mass: the mass of one mole of substance in kg mol^{-1}
Molecular mass: the mass of a molecule in u (atomic mass unit)

Ideal gas law: $pV = nRT$, $pV = NkT$

The pressure law (constant volume): $\frac{p}{T} = \text{constant}$

Charles' law (constant pressure): $\frac{V}{T} = \text{constant}$

Boyle's law (constant temperature): $pV = \text{constant}$

Work done on a gas: $W = p\Delta V$

Avogadro's constant (N_A) is the number of atoms in 12 g of carbon isotope ${}^{12}_{6}C$.
An isotope's or chemical's **molar mass** describes how much mass is in **N_A molecules** of that chemical.

The **Boltzmann constant (k)** is related to Avogadro's constant by $k = \frac{R}{N_A}$

p = pressure of the gas
V = volume of the gas
T = temperature of the gas
n = number of moles in a gas
N = number of molecules in a gas
W = work done on the gas
N_A = Avogadro's constant = 6.02×10^{23} mol^{-1}
R = gas constant = 8.31 J K^{-1} mol^{-1}
k = Boltzmann constant = $\frac{R}{N_A} = 1.38 \times 10^{-23}$ J K^{-1}

Molecular kinetic theory model

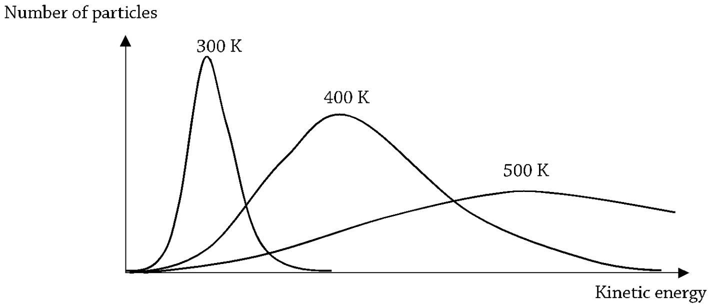
The molecular kinetic theory applies the gas laws to **individual molecules**. Molecules in a fluid are in **constant random, rapid motion**.
The kinetic theory is based on a statistical mathematical model, so only applies to large numbers of particles.

Kinetic theory equation

The kinetic theory equation gives the pressure of an ideal gas in terms of the **root mean square velocity** of the particles in the gas. Root mean square velocity is a way of taking an average of all the speeds of the particles.

$$p = \frac{Nm}{3V}\overline{c^2}$$

$\overline{c^2}$ = root mean square velocity



The **Maxwell–Boltzmann distribution** shows the number of particles with a given kinetic energy. At higher temperatures, there are still particles with lower kinetic energies, but there are far more particles with higher kinetic energies so the average kinetic energy is higher overall.

Mc

Pressure law:

Charles' law:

Boyle's law:

Average molecul kinetic e

Internal an ideal

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Periodic motio

Circular motion

For an object to move with **circular motion** the object must continually deviate from its straight line direction and, therefore, continuously **change its velocity**.

This implies that there is acceleration, and to accelerate a force must be exerted on the object.

The force that causes an object to maintain circular motion is called a **centripetal force**.

The centripetal force **always** acts towards the **centre** of rotation.

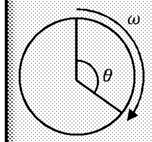
A relationship between radians and degrees is:

$$radians = degrees \times \frac{\pi}{180}$$

Angular quantities

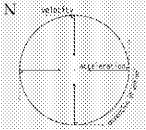
Angular velocity:	$\omega = \frac{v}{r} = 2\pi f$
Centripetal acceleration:	$a = \frac{v^2}{r} = \omega^2 r$
Centripetal force:	$F = \frac{mv^2}{r} = m\omega^2 r$

These equations are in the data booklet!



For constant speed in a circle
$v = \omega r$

v = linear speed, in m s⁻¹
r = radius of circular path, in m
ω = angular velocity, in rad s⁻¹
f = frequency, in Hz
a = centripetal acceleration, in m s⁻²
F = centripetal force, in N

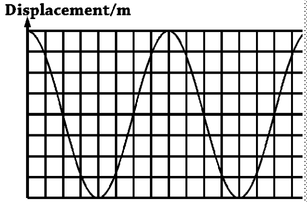


An object with an **angular frequency** (sometimes called angular speed), **ω**, of 1 rad s^{-1} moves through one radian of a circle in one second.

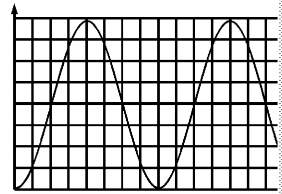
For a circle of a radius of 2π metres, this corresponds to moving 1 m around the circumference of the circle.

An object that goes around an entire circle in 1 s has ω = 2π **rad s^{-1}**.

Simple harmonic motion is which acceleration is **propor** and **opposing in direction t**

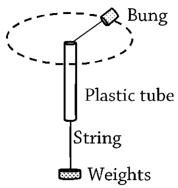


displacement = x = A cos ωt



acceleration = a ∝ −A cos ω

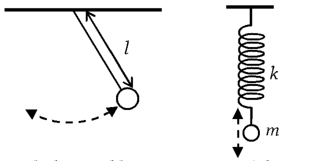
Investigating circular motion



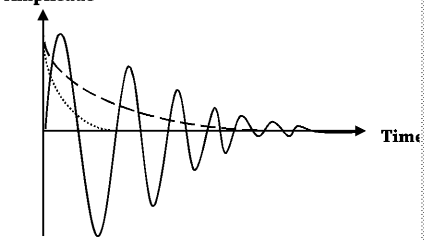
- Mark a point on the string
- Hold the plastic tube and 'whirl' the bung around
- Vary the speed until the mark just appears
- Measure the time for 10 rotations of the bung and determine the speed of the bung
- Add weights and repeat

Investigating simple harmonic motion

- For a spring–mass system or pendulum:



- Mark the equilibrium position of the system
- Move the mass away from its equilibrium position
- Measure the time for 10 oscillations past the marker
- Divide by 10 for the period of one oscillation

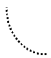


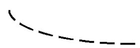
Damped oscillations

Oscillations of systems will eventually **lose their am** due to resistance from friction or air resistance.

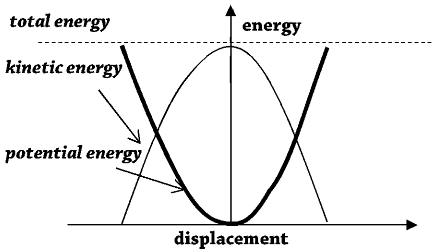
Light damping:

the time period is **independe** and, therefore, each wave cycle of time for oscillations to decre

Critical damping:

the **minimum amount of da** oscillation to stop over the cou after being released.

Heavy damping:

damping that is **stronger tha** and causes the system to retur **longer amount of time** than

Energy–displacement graphs of SHM for free oscillations

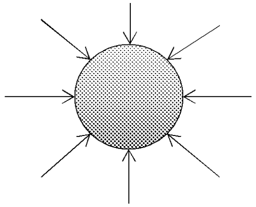


The **total energy** of a simple harmonic system is constant. At minimum displacement, speed is at a maximum and so **kinetic energy** is maximum. Kinetic energy is converted to **potential energy** as displacement increases.

Gravitational fields

Gravitational fields

Gravitational fields are generated by all masses, and affect all masses.



Radial field: A field that is spherical and **acts towards a central point**. Gravitational fields are radial. A radial gravitational field around a planet can be seen to the right.

Uniform field: A field that has **no variation**. Gravitational fields are approximated as uniform near the surface of planets.

In the case of gravitational fields, a **field line** gives the path that a smaller mass takes towards a larger mass due to the force of gravity. A higher density of field lines shows a stronger gravitational field, and a stronger force that a mass will experience.

Exam Tip!

A spherical object can be treated as a point particle with its entire mass at its centre.

Gravitational field strength

The gravitational field strength, g, is the force, F, per unit mass, m, on an object in a uniform gravitational field.

$$g = \frac{F}{m}$$

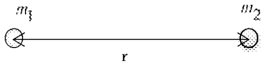
The gravitational field strength of the Earth near the surface is 9.81 N kg^{-1}.

The magnitude for g in a radial field is:

$$g = -\frac{GM}{r^2}$$

Newton's law of gravitation

Gravity is the universal attractive force that acts between all matter.



Newton determined the **force of gravitation** between two masses to be:

$$F = \frac{Gm_1m_2}{r^2}$$

F = force due to gravity
G = gravitational constant = 6.67×10^{-11} N m^2 kg^{-2}
m_1 = mass of object 1
m_2 = mass of object 2
r = distance between centres of mass

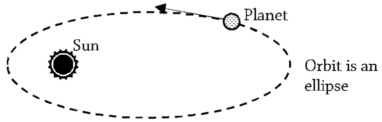
So the force due to gravity

- increases with mass
- decreases with distance

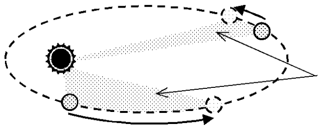
Kepler's laws of planetary motion

Kepler's laws describe the motion of orbiting bodies, such as planets around the Sun.
Kepler's laws are:

1. A planet orbits the Sun in an elliptical orbit, with the Sun at one the focal points of the orbit.



2. The area swept out by a line connecting the Sun and a planet sweeps out a constant area in a given time.



This shows the movement of the planet during two equal periods of time.
Planet travels faster when closer to the Sun, so that both shaded areas are of equal size.

3. The period of a planet's orbit squared is proportional to the average radius of the planet's orbit cubed, or:

$$T^2 \propto r^3$$

$$T^2 = \left(\frac{4\pi^2}{GM}\right) r^3$$

Kepler's laws apply to any orbital system, such as moons or galaxies.

For orbiting bodies, the centripetal force allowing orbit to occur is the gravitational force of the body at the centre of the orbit.

Derivation of Kepler's third law

$$F_{centripetal} = F_{gravitati}$$

$$\frac{mv^2}{r} = \frac{GMm}{r^2}$$

$$v^2 = \frac{GM}{r}$$

$$\left(v = \frac{2\pi r}{T}\right)$$

$$\frac{4\pi^2 r^2}{T^2} = \frac{GM}{r}$$

$$T^2 = \left(\frac{4\pi^2}{GM}\right) r^3$$

Geostationary satellites

A **geostationary satellite** is a satellite that has an **orbital period** around Ea equator of **one day** (24 hours).

Since the rotational period is also 24 hours, then the satellite stays at a **fixed position** above Earth's equator.

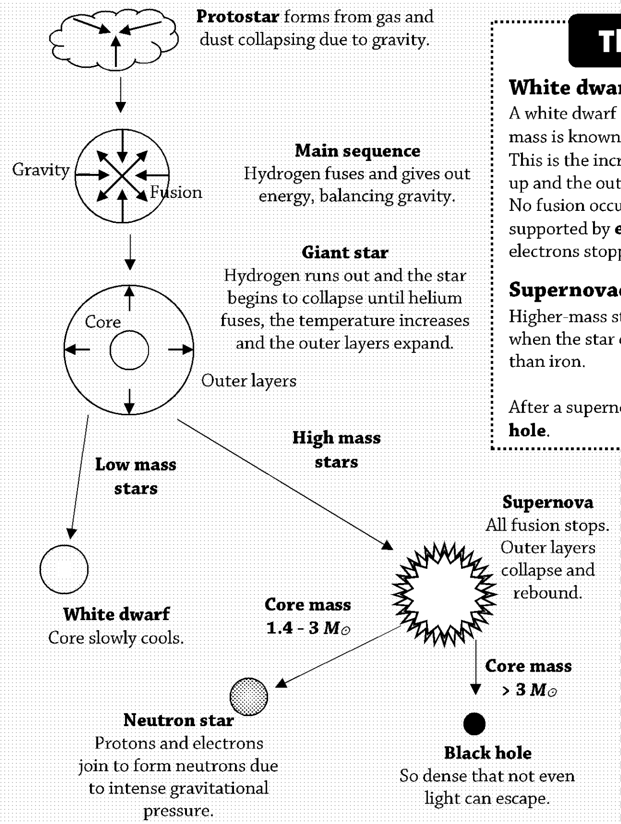
The distance of a geostationary satellite above Earth can be found using **Kepler's third law** derived above.

Geostationary satellites are used in **communications** and **navigation systems**, such as the satnav that is used in ca

Geostationary satellites have to orbit at a set distance so that their centripetal acceleration is equal to the acceleratio to gravity. This can be found by equating the two.

Stars

Life cycle of a star



The deaths of stars

White dwarfs

A white dwarf is the leftover core of a star, with a mass of up to 1.4 $M_\odot$. This mass is known as the **Chandrasekhar limit**.
This is the incredibly **hot core** of the star, formed once all the fuel has been used up and the outer layers of a red giant are thrown out into space.
No fusion occurs, but the core does not collapse. This is because the core is supported by **electron degeneracy pressure** – the repulsive forces between electrons stopping them getting any closer together.

Supernovae

Higher-mass stars undergo a **supernova** stage – an incredibly bright explosion when the star collapses in on itself, which triggers fusion of elements heavier than iron.

After a supernova, the core left behind can be either a **neutron star** or a **black hole**.

Neutron stars

If the core left over after a supernova has a mass of 1.4× to 3.0× solar masses, it forms a neutron star, with a radius of about 10 km.
In the core of a neutron star, gravity is so great that protons and electrons are forced together to become neutrons.

Black holes

If the core left over is heavier than 3× solar masses, it forms a black hole. A black hole produces such a strong gravitational field that nothing can escape, not even light.
The surface around a black hole from which nothing can escape is called the event horizon.

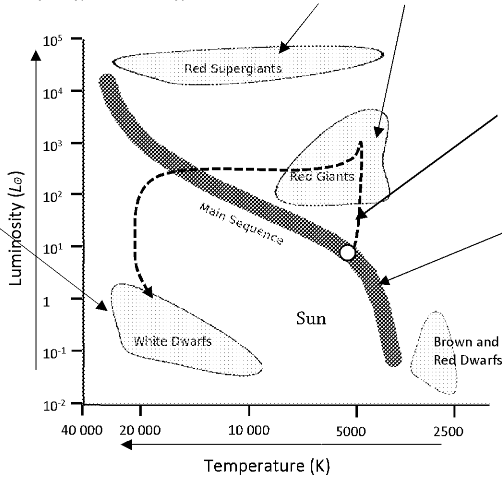
The Hertzsprung–Russell (HR) diagram

A diagram showing stars categorised by temperature and brightness.
Stars fall into several groups on the Hertzsprung–Russell diagram.

Giant stars are large and bright.
The cooler **red giants** fuse helium in their cores, and form after main sequence stars run out of hydrogen.
Hotter **supergiants** are higher mass giant stars.

White dwarfs are the incredibly hot cores of stars which **no longer undergo fusion**.

White dwarfs gradually cool and radiate all their heat, and become black dwarfs.



Evolution of a main sequence star, such as the Sun

All stars spend **most of their lives** in the main sequence.
This is when they **fuse hydrogen into helium**.
Most stars, including the Sun, are on the main sequence. **Red dwarfs** are the smallest and coolest main-sequence stars.

Brown dwarfs are starlike objects with **masses too low** to sustain fusion of hydrogen.

Exam Tip!

The x-axis is logarithmic and decreases in temperature from left to right.

The y-axis is measured in terms of our Sun's luminosity ($L_\odot$), which increases in brightness going up the axis.

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$n = ($
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Black-b

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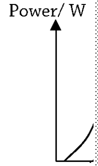
radiatio
- Hot obj
- A black
incident
- A star is



Wien

λ_{ma}

Exampl
The Sun
of power
$T = \frac{2.9}{\lambda}$
$\frac{L}{4\pi r^2} = c$

Cosmology

Distances in astrophysics

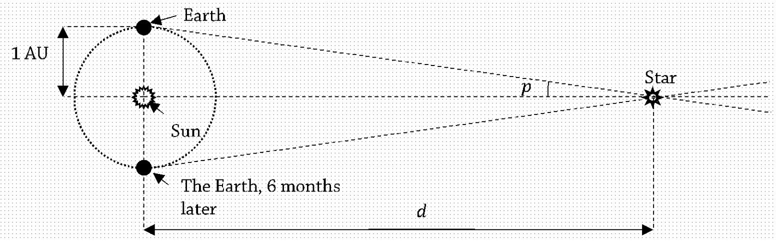
When discussing objects in space, units like metres and kilometres start to become unhelpful, as they're so much smaller than the distances we want to talk about! Instead we use units like **astronomical units**, **light years** and **parsecs**.

Astronomical unit (AU): The distance between the Earth and the Sun
Light year (ly): The distance travelled by light in a year
Parsec (pc): The distance to a star that subtends an angle of 1 arcsecond as seen from Earth as it orbits the Sun.

$1\ \text{AU} = 1.50 \times 10^{11}\ \text{m}$
$1\ \text{ly} = 9.46 \times 10^{15}\ \text{m}$
$1\ \text{pc} = 3.08 \times 10^{16}\ \text{m}$
$1\ \text{pc} = 2.06 \times 10^{5}\ \text{AU} = 3.26\ \text{ly}$

Stellar parallax

As Earth orbits the Sun, the positions of nearby stars appear to shift against a fixed background of distant stars. This effect is called **parallax**.



d is very big compared to 1 AU

By trigonometry,

$$\tan p = \frac{1\ \text{AU}}{d}$$

so

This uses the small angle approximation $\tan\theta \approx \theta$

$$p = \frac{1}{d}$$

$p =$ parallax, in seconds of arc
$d =$ distance in parsecs

Cosmological principle

The cosmological principle is a simple but useful idea, without which astrophysics would be impossible.

The cosmological principle states:

- The universe is **homogeneous** – its density is relatively uniform on a large scale.
- The universe is **isotropic** – it looks the same when looking in any direction and from any point.
- The laws of physics are **universal**.

This is important because it means that we can apply what we see in our own galactic neighbourhood to other areas of the universe.

The cosmological principle is an acknowledgement that there's nothing especially important about the Milky Way or our position in it – if there were, we wouldn't be able to assume anything about what we see in other areas of the universe, because the laws of physics might be different.

Exam Tip!

This is a rough estimate of the age of the Universe! There are other ways to give an indication about the Universe's ages, such as by estimating the ages of the oldest galaxies by their compositions.

($H_0 \approx 70\ \text{km s}^{-1}\ \text{Mpc}^{-1} = 2.27 \times 10^{-18}\ \text{s}^{-1}$)

The Doppler effect is the change in o
This can be observed in light from dista

- Light from stars moving away from called **red shift**.
- Light from stars moving towards us

Doppler effect:

(for $v \ll c$)

$z = \frac{\Delta\lambda}{\lambda} \approx$

Hubble's law

By comparing the velocity of differe away from Earth.

Hubble's law:

This recession of galaxies suggests t in space is moving away from every

On a small scale, this expansion is c and electrostatic forces, so individu be seen on a cosmological scale.

The Big Bang theory is a theory of how t theory says that at the start of the universe compressed to a single point. This singular it is this expansion that is the cause of the

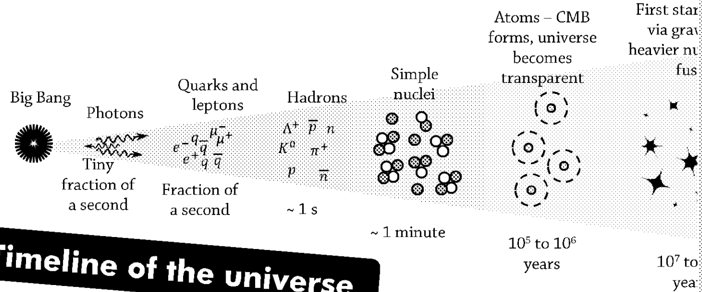
Age of the universe

- Assume H_0 is constant
- d is the distance the furthest galaxies move away from the initial singularity
- v is the velocity at which these galaxie
- This gives

$$t_{Universe} = \frac{d}{v} = \frac{1}{H_0}$$

$$t_{universe} = \frac{1}{2.27 \times 10^{-18}} = 4.4 \times 10^{17}$$

Timeline of the universe



Capacitors

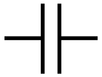
Capacitance

A **capacitor** is an electrical device that **stores charge**. Capacitors are useful for storing energy and 'smoothing' AC signals in power generation.

In a capacitor, a current causes negative charge to build up on the negative plate, and positive charge to build up on the positive plate. The current never flows through the capacitor itself.

Capacitance, C, of a capacitor is defined as the **charge stored, Q, per unit potential difference, V.** The greater the potential difference needed to store a unit charge, the lower the capacitance.

In a circuit, a capacitor is symbolised by two parallel lines



$$C = \frac{Q}{V}$$

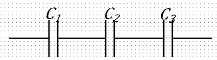
C = capacitance
Q = charge stored
V = potential difference across capacitor

Combining capacitors

Combining multiple capacitors in a circuit can be modelled as having a single capacitance.

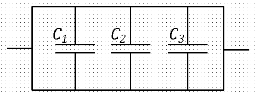
For capacitors in series:

$$\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots + \frac{1}{C_n}$$

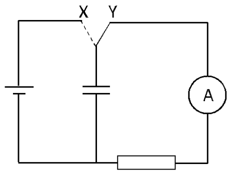


For capacitors in parallel:

$$C_{total} = C_1 + C_2 + C_3 + \cdots + C_n$$



Measuring capacitance



This circuit can be used to investigate capacitance.

When the switch is **connected to X**, the **capacitor charges**, and when it is **connected to Y**, the **capacitor discharges across the resistor**.

By calculating the maximum potential across the capacitor and total charge held by the capacitor, we can find the capacitance of the capacitor and energy stored by the capacitor.

By attaching the voltmeter and ammeter to a **data logger** we can collect data for graphs of charge, potential difference and current as the capacitor charges and discharges.

Energy stored by capacitor

When a capacitor is charged, energy is stored in the capacitor as **electric potential energy**.

The energy stored by a capacitor increases with both charge stored and potential difference across the plates.

Energy stored:

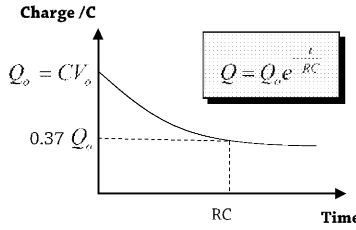
$$E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$$

Incredibly large capacitors known as **super capacitors** can even be used as batteries to store energy for later usage.

Capacitor charge and d

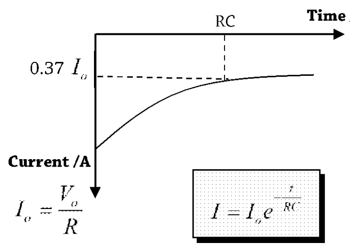
As a capacitor is charged or discharged, the charge s potential difference across the capacitor and curren capacitor follows exponential decay relationships.

Discharging a capaci



$$Q = Q_o e^{-\frac{t}{RC}}$$

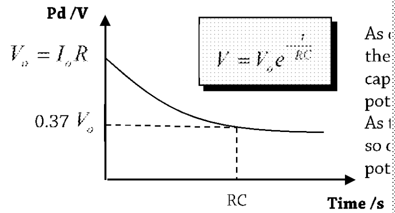
As a cha exp cha fiel anc for



$$I = I_o e^{-\frac{t}{RC}}$$

Cur cha bec the

The dec fro



$$V = V_o e^{-\frac{t}{RC}}$$

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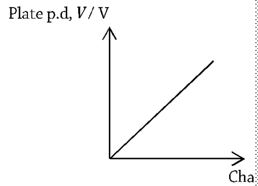
Voltage–charge g



Gradient of $V - Q$ graph $= \frac{Q}{V}$

Area under $V - Q$ graph $= \frac{1}{2}QV$

Electric field strength

Electric fields arise due to a charged object and can be represented by field lines that show the **path a positive charge would take** if placed in the field. When a charged object is in the presence of an electric field it will experience an electrostatic force that is exerted by the field.

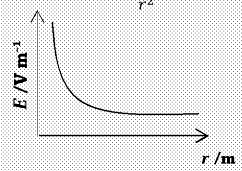
Electric field strength is defined as the **force, F, per unit charge, Q**, in the field:

$$E = \frac{F}{Q}$$

E = electric field strength
F = force on charge
Q = charge

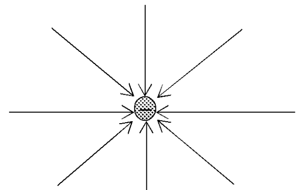
***E–r* graph**

$$E \propto \frac{1}{r^2}$$



So a greater electric field strength produces a larger force on a charge.

Radial fields

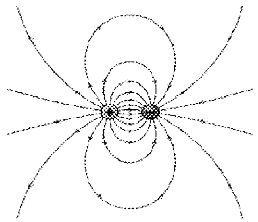


The radial field around a negative point charge.

It is attractive because electric fields are always drawn with reference to a positive point charge.

The electric field strength created by a point charge is given by

$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$



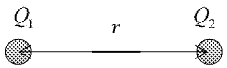
The field lines of a positive and negative charge brought close together.

A positive charge would be attracted to the negative charge and repelled from the positive charge.

Coulomb's law

Coulomb's law gives the **electric force between two charges**

$$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2}$$



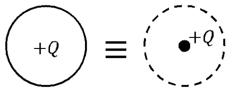
where ε_0 is a constant called the **permittivity of free space**.
$\varepsilon_0 = 8.85 \times 10^{-12}$ F m⁻¹

Therefore, the force between two charges follows the **inverse square law**.
Force increases with greater charge or smaller distance.

F = force Q = charge r = distance between charges

Exam Tip!
Air can be considered a vacuum when determining forces between charges

Exam Tip!
A charged sphere can be modelled as a point charge at the centre of the sphere



Exam Tip!
Attractive forces are negative, repulsive forces are positive

Electric and gravitational fields

Electric and gravitational fields have many similarities!

	Gravitational	Electrostatic
Source of force field	Mass	Charge
Interaction	Masses always attract	Charges can attract or repel
Force	Inverse square law relationship with respect to distance between masses $F = \frac{GMm}{r^2}$	Inverse square law relationship with respect to distance between charges $F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2}$
Field strength	Force per unit mass	Force per unit charge
Potential in radial field	Always less than zero	Sign depends on the charges

El
pc
Tl

V /V

Work done to move charge

$$\Delta W = Q\Delta V$$

A potential difference of 1 V
do 1 J of work on a charge of

Dielectrics are any insulating materials
store a charge.

A **parallel plate capacitor** is comprised
conducting plates with a dielectric in bet

The relative permittivity (dielectric const
defined as a ratio of the capacitance of tl
capacitance of the same volume of free s

A dielectric with a high relative permitt
Dielectrics tend to be good electrical in

For a parallel plate capacitor, capacitan

$$C = \frac{A\varepsilon_0\varepsilon_r}{d}$$

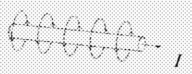
A = area of p
ε_0 = permitt
= 8.85 × 1
ε_r = relative
dielectri
d = distance

Electromagneti

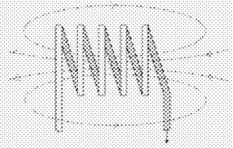
Magnetic flux density

Magnetic field lines are used to map magnetic fields.

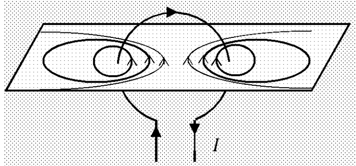
Magnetic field around a current-carrying wire



Magnetic field around a current-carrying solenoid



Magnetic field around a current-carrying flat loop



Magnetic flux density: is the **force per unit length per unit current** on a current-carrying conductor at right-angles to a magnetic field

Force on a current-carrying wire in a magnetic field:

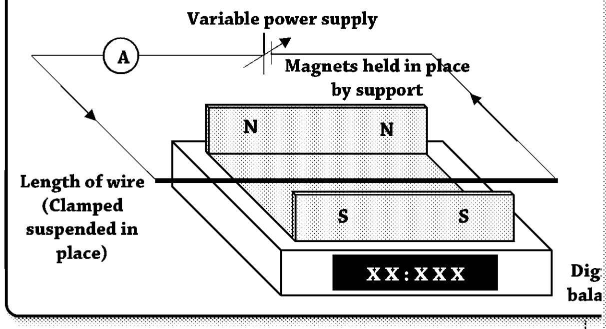
$$F = BIL\sin\theta$$

F = force on wire
B = magnetic field strength
I = current through wire
L = length of wire
θ = angle between wire and field

Investigation of force of a wire

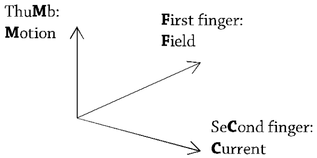
The set-up below can be used to investigate the effect of current on magnet force generated.

The current is varied, and the change in weight of the magnets is recorded - change in weight is due to the force of the magnetic field generated by the



Fleming's left-hand rule

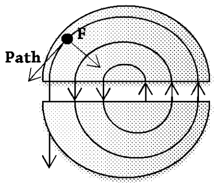
The rule allows you to determine the direction of motion, field and current in relation to one another:



Exam Tip!
Remember that current is reversed for a negative charge

Charges moving in circular paths

If a charge moves in a circular path in the presence of a magnetic field, we know that the force acting on the particle must be acting towards the centre of the circle.
The magnetic field is being used to control the path direction of the moving charge.
This concept is used in devices such as cyclotrons used in medical machinery to provide radiotherapy treatment
Cyclotrons can accelerate radioactive particles and control the direction of the particle beam in order to accurately hit the target area on a patient.



Magnetic field directed into the page for a positive particle

Centripetal force supplied by the force exerted by the magnetic field

$$r = \frac{mv}{BQ}$$

r = radius of particle path
m = mass of particle
v = speed of particle
B = magnetic field strength
Q = particle charge

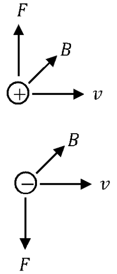
Moving charges in a magnetic field

Force on charged particles moving in a magnetic field:

$$F = BQv$$

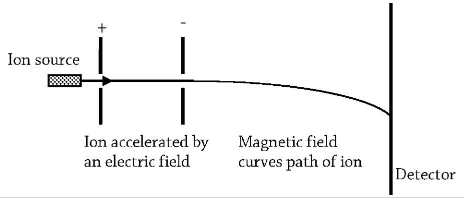
F = force on particle
Q = particle charge
B = magnetic field strength
v = particle velocity

For a magnetic field directed **into the page**
a **positive** charge moving to the **right** would experience a force **upwards**
a **negative** charge moving to the **right** would experience a force **downwards**



Exam Tip!
The above equations are only applicable if the particle is moving perpendicular to the direction of the field

Velocity selector
In a velocity selector, an ion is accelerated across an electric field, and then its path is curved by a magnetic field until it hits a detector. The radius of the ion's path, and hence where it hits the detector, is determined by its mass.



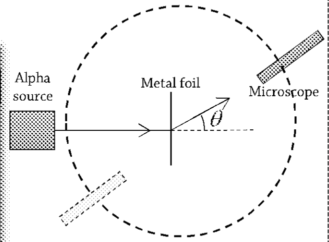
Nuclei

Rutherford scattering

Rutherford's scattering experiment in 1908 provided new evidence about the structure of the atom and resulted in the scientific community moving on from J J Thomson's plum pudding model of the atom and adopting Rutherford's model.

The experiment

An alpha source provided a **beam of alpha particles** that were aimed at a thin piece of **gold foil**.
All alpha particles (positively charged) were of the **same energy** and the experiment was carried out in an **evacuated chamber**.
The alpha particles were **detected** by a detector that remained at a **fixed radial distance** from the point of collision between the particles and the foil.
Light was emitted when the particles hit the detector and these emissions of light could be seen by a microscope.



The results

A small portion of alpha particles were **deflected by the foil through angles greater than 90°**.
The majority of alpha particles passed through the foil, some with **no deflection** and some with a **small angle of deflection**.

The conclusions

The majority of particles passed through the foil, which shows that the atoms making up the foil are likely **mostly empty space**. Most of the mass of the atom is concentrated in a small **nucleus** at the centre of the atom.
Some alpha particles were deflected, which suggests that the **nucleus must be positively charged**, as the positively charged alpha particles were repelled as they approached the nucleus.

Nuclear radius

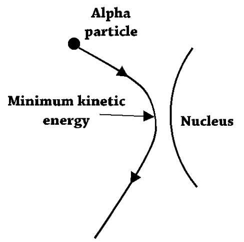
Estimates of nuclear radius can be determ
the **closest approach of alpha particle**

The nucleus has a radius of around ~**10**⁻

Closest approach of alpha particles

Alpha particles are directed towards the atom and are deflected due to electrostatic repulsion.

The kinetic energy, E_k, **of the alpha particle will reduce and the** potential energy, E_p, **will increase.**

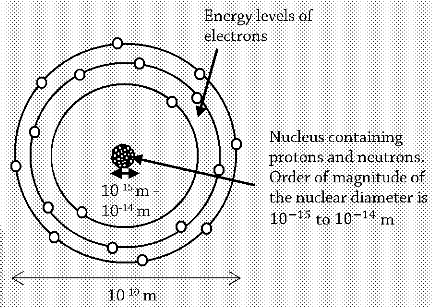


Constituents of an atom

Simple model of an atom

An atom is made up of:

1. a nucleus, where most of its mass is concentrated, that is comprised of protons and neutrons
2. electrons that sit in shells outside the nucleus



Charge and mass of constituent parts

	Charge/ C	Mass/ kg
Electron	-1.6×10^{-19}	9.11×10^{-31}
Proton	$+1.6\times10^{-19}$	$1.67(3)\times10^{-27}$
Neutron	0	$1.67(5)\times10^{-27}$

Specific charge: the ratio of charge of an ion or particle to its mass

Isotope: two or more of the same element with the same number of protons but a different number of neutrons in their nuclei

Nuclide notation

Nuclei can be written in the following form:

$${}^{A}_{Z}X$$

where A is the mass number (number of nucleons) and Z is the proton number (number of protons).

Strong nuclear
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Unstable nucle
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Particles

Particles and antiparticles

For every particle there is an antiparticle. A particle's antiparticle has an equal but opposite charge, and the same rest mass and energy as its particle counterpart.

Photon energy:

$E = hf$

$f = \frac{c}{\lambda}$

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

Properties of antiparticles

	Particle	Charge, q	Rest mass, m_0	Rest energy, E_0
Positron	Electron	$+1.6 \times 10^{-19}$ C	9.11×10^{-31} kg	0.511 MeV
Antineutron	Neutron	0 C	$1.67(5) \times 10^{-27}$ kg	939.6 MeV
Antiproton	Proton	-1.6×10^{-19} C	$1.67(3) \times 10^{-27}$ kg	938 MeV
Antineutrino	Neutrino	0 C	0 kg	0 eV

Pair production

Pair production occurs when a photon creates a particle and its corresponding antiparticle, disappearing in the process.

$hf_{min} = 2E_o$

A photon with energy, $E < 2E_o$ could, therefore, not create a particle–antiparticle pair.

Annihilation

Annihilation occurs when a particle and its corresponding antiparticle meet.
Their individual masses are converted into the radiation energy of two photons.

$2E_o = 2hf_{min}$

Antibaryons

3 antiquarks

- Protons and neutrons a
  baryons.
- Proton is the only stabl
- All other baryons event
  protons.
- Examples of antibaryor
  and antineutrons.
- Baryons have a baryon
  whereas antibaryons ha
  number of -1.
- All hadrons are affectec
  force and the strong nu

Quarks

	Symbol	Charge	Baryon number
Up	u	$+\frac{2}{3}$	$+\frac{1}{3}$
Down	d	$-\frac{1}{3}$	$+\frac{1}{3}$
Strange	s	$-\frac{1}{3}$	$+\frac{1}{3}$

Quarks and antiquarks

Quarks: elementary particles that are the smallest known constituents that make up matter. There are three types of quarks you need to know.

Quark composition

- Neutron: udd
- Proton: uud
- Antineutron: $\bar{u}\bar{d}\bar{d}$
- Antiproton: $\bar{u}\bar{u}\bar{d}$
- Pion: $u\bar{d}$ (π^+); $u\bar{u}$ or $d\bar{d}$ (π^0); $d\bar{u}$ (π^-)
- Kaon: $u\bar{s}$ (K^+); $d\bar{s}$ or $s\bar{d}$ (K^0); $s\bar{u}$ (K^-)

You would be expected to know the decay of a baryon in terms of quarks

Application of conservation laws

Conservation law decays/interacti

- Conservation of energy, momentum to all changes.
- In any interaction, baryon and lepto conserved.
- Strangeness must be conserved in s but not weak interactions.

Radioactive de

Types of decay

Alpha decay:

$$^A_ZX \rightarrow {}^{A-4}_{Z-2}Y + {}^4_2\alpha$$

Beta decay:

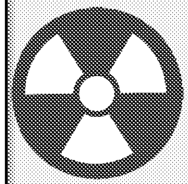
$$^A_ZX \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta + \bar{\nu}$$

Gamma decay:

$$^A_ZX^* \rightarrow {}^A_ZX + \gamma$$

Background radiation

- A low level of radiation is always around us, from both natural and man-made sources of radiation.
- **Sources of background radiation**:
  Natural: Nuclear materials in ground, cosmic rays
  Man-made: Buildings, nuclear power plants, medical nuclear applications
- When calculating the amount of radioactivity present due to a source it is important, therefore, that the **background radiation is measured first** and that this value is **taken away** from the radioactivity measured when the source is present.



Type of radiation	Consists of	Range in air	Ionisation	Absorption	Applications
Alpha	Two protons + two neutrons	<10 cm	Creates around 10^4 ions per cm in air	Stopped by thin metal foil or paper	Thickness measurements of paper Used in smoke detectors
Beta	Electron or positron	<1 m	Creates around 100 ions per mm in air	Stopped by 3–5 mm of aluminium	Thickness measurements of aluminium foil
Gamma	Photon of energy	Obeys inverse square law $\left(1/_{r^2}\right)$	Weakly ionising	Stopped by several cm of lead	Used in medicine to image internal structure of the body

Radioactive decay

Radioactive decay occurs when an atom is unstable, and emits radiation to obtain a **more stable state**.

Radioactive decay is a **random process**. This means that we can't know which nucleus in a sample will decay next, or when.

Decay probability: $\frac{\Delta N}{\Delta t} = -\lambda N$

Number of unstable nuclei: $N = N_0 e^{-\lambda t}$

$N =$ *number of atoms in sample*
$N_0 =$ *initial number of atoms in sample*
$\lambda =$ *decay constant*
$t =$ *time*

Activity A:

the number of unstable nuclei that decay per second in a given sample:

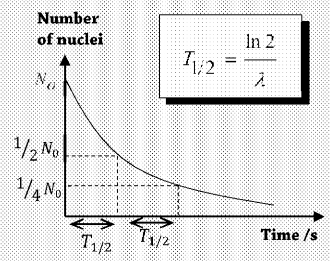
$$A = A_0 e^{-\lambda t} \qquad A = \lambda N$$

The **half-life ($T_{1/2}$)** of a radioactive substance is the amount of time it takes for the activity of the substance to decrease to **half its original value**. Half-life is a constant, no matter the amount of substance left.

Half-life is used in medicine to determine which isotope to use to image inside a patient's body as the source needs only to be radioactive as long as the imaging takes and then should have as little radioactivity as possible.

It is also used in areas such as **carbon dating**. All living organisms have a roughly equal ratio of ^{12}C to ^{14}C in their bodies. When they die, the ^{14}C slowly decays. By examining the amount of ^{14}C left in a sample, its age can be determined.

$$T_{1/2} = \frac{\ln 2}{\lambda}$$



- N
t
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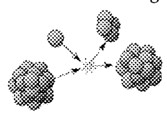
binding energy per nucleon than the low mass
temperatures and pressures than fission, so is
- **Nuclear fission:** a large unstable nucleus
nuclei. The binding energy per nucleon will



Knowledge of the
scientists to mak
energy use as an

Induced fission

Fission
isotop

The uranium isotope is split into **two small**
roughly equal mass and two or three **fission**
Fission (thermal) neutrons can be harnessed
Chain reactions only occur if the material us
With each fission event huge amounts of en
Fission chain reactions are used in **nuclear**

The thermal n

- The **moderator** controls the speed of the n
value in order to induce fission. Graphite o
low probability of absorbing neutrons a
- The **control rods** absorb neutrons to ensu
each fission event. They have the ability to
release of energy needs to be reduced. The
ability to **absorb neutrons effectively**.
- The **coolant** extracts the heat and allows it
electricity. Coolant is usually water or carb
specific heat capacity of the
materials.

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Medical imagi

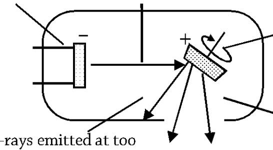
X-rays

X-rays are produced by accelerating electrons through a potential and colliding them with a metal target – as the electrons hit the target and suddenly decelerate, their kinetic energy is converted to X-rays.

Electrons are released via thermionic emission – the cathode heats up and releases electrons.

As the electrons are accelerated, they gain energy, $E = eV$.

If all of this energy is converted to the energy of the X-ray, the energy of the X-ray will be $eV = hc/\lambda$.



X-ray attenuation

As X-rays pass through matter, they are absorbed.

The intensity of the beam decreases exponentially.

Attenuation:

$$I = I_0 e^{-\mu x}$$

I is the beam intensity
x is the distance through the materials
μ is the linear attenuation coefficient
$\mu_m = \frac{\mu}{\rho}$ is the mass attenuation coefficient

Attenuation

Simple scatter:	1–20 keV. X-rays are absorbed and re-emitted by atoms without changing energy, only direction.
Photoelectric effect:	< 100 keV. X-rays are absorbed by an electron which then leaves the atom.
Compton effect:	0.5–5.0 MeV. X-rays are partly absorbed by an electron leaving the atom, and which is scattered with reduced energy.
Pair production:	>1.02 MeV. X-rays are converted into an electron–positron pair when approaching the nucleus.

Detection

X-ray film will react with X-rays by changing from white to black.

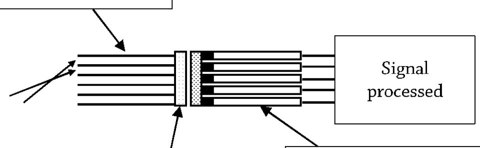
A contrast medium is used to increase the contrast of an image. A patient will ingest a sample of barium or iodine, which is opaque to X-rays so shows up well. This gives greater detail.

Gamma camera

Gamma cameras are used to detect radiation emitted by radionuclide tracers.
A tracer commonly used with gamma cameras is technecium-99m.
This is a short-lived isotope which gives off gamma rays.

$$^{99m}Tc \rightarrow {}^{99}Tc + \gamma$$

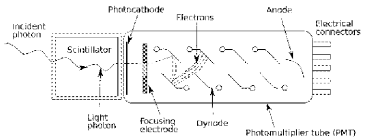
Techecium-99m can be attached to biological molecules, meaning it can easily be made to move to specific sites in the body. ^{99m}Tc has a half-life of around six hours, so doesn't stay in the body too long.



Collimator removes photons travelling at an angle

Scintillator produces many more photons, amplifying the signal

Photons travel through **light guide** and **photomultiplier tube array**, converting the photons into an electrical signal to be processed



In a photomultiplier tube, a photon is converted into an electron, which is then amplified into a cascade of electrons.

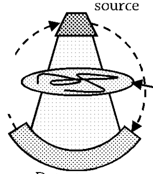
CT scans

A CT scan involves a series of narrow beams of X-rays passed over the patient.

Each beam produces a 360° image of a 'slice' of the patient, and the camera then moves on produce another 360° of the next 'slice'.

CT scans are much slower and more expensive than traditional X-rays, but produces 3D im much higher detail.

Source and detector move around patient



In a **PET scan**, a positron-emitting trac
Fluorine-18 is a tracer often used, whic

The positron emitted in this decay quic
Two gamma rays are emitted at 180° fr

^{18}F is used as it can form a molecule call
quickly moves towards areas of the bod

Ultrasound is sou
20 kHz – outside t
Ultrasound scans
body non-invasivel
At each tissue bou
The amount of ene
specific acoustic in
The reflections can

A-scans are single
The reflected energ
If the speed of sour
to the boundary ca

B-scans are a rapid
The scans are swept
The reflected energ
brighter areas are d

Uses
To see babies in th
To scan organs suc

A special gel is
skin to reduce
because the ge
– it has the sar
of skin, so fills
doesn't pass th

Thermal physi

Absolute zero

1. a) What is meant by the term 'absolute zero'?

b) What is the value of absolute zero in kelvin and in Celsius?

2. Convert:

a) 84.5 °C to K.

b) 114 K to °C.

c) 3520 °C to K.

States of matter

3. Describe solids, liquids and gases below, including a diagram of the particles in each state.

Solids

Liquids

Gases

4. State what is meant by Brownian motion.

5. Outline an experiment that could be used to determine the **specific heat capacity** of a substance.

6. Outline an experiment that could be used to determine the **specific latent heat** of a substance.

7. Define what is mea

8. During a camping t
1030 J of heat is pu
The water does 480
What is the differer

9. State the first law o

10. A bowl containing 1.

Over time, the ice cul

The specific heat cap
3.36×10^5 J kg^{-1}.

a) Calculate the ener

b) What can be said

c) Calculate the ener

d) Explain what hap

Ideal gases

Ideal gas laws

1. Explain the difference between molecular mass and molar mass.

2. A 6.5 m^3 oxygen canister is kept at a pressure of 15,200 kPa and a temperature of 20 °C.

Calculate the number of moles in the canister.

$R = 8.31\ J\ mol^{-1}\ K^{-1}$

3. 0.34 J of work is done on a gas, compressing it to a volume of 48 cm^3, at a constant pressure of 950 Pa. Calculate the initial volume of the gas.

4. a)

b)

c)

5. Describe how Charles' law can be investigated.

Molecular kinetic theory model

6. Use the molecular kinetic theory model to explain each of the three gas laws.

7. A sample of helium is at 10.0 °C.

The molar mass of helium is 0.00400 $kg\ mol^{-1}$.

Note: $k = 1.38 \times 10^{-23}\ J\ K^{-1}$

a) Calculate the kinetic energy of a helium molecule in the sample.

b) Calculate root mean square velocity of the helium molecule.

c) Calculate the total kinetic energy for 5.00 moles of helium.

Periodic motic

Circular motion

1. Explain how an object or a system can remain in a circular path.

Angular quantities

2. A vibrating string is oscillating with a frequency of 20.0 Hz. Calculate its angular speed.

3. A geostationary satellite takes 24 hours to orbit Earth. The geostationary satellite is in circular orbit with a radius of 42, 157 km.

a) Calculate the speed of the satellite around Earth.

b) Explain how the satellite is able to maintain a circular orbit around Earth.

c) Calculate the centripetal acceleration.

4. Wha

5. Calc displ

6. The repr simp

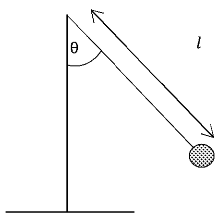
a)

b)

c)

Simple harmonic systems

7. A clock pendulum is swinging back and forth, and is shown here at its maximum amplitude.



a) What can be said about the relationship between the pendulum's acceleration and its displacement from the equilibrium position?

b) Sketch on the diagram the direction of the centripetal force.

c) Explain how the kinetic energy and potential energy will change during the oscillation.

Damped oscillations

8. What is a damped oscillation?

9. Sketch a graph of displacement against time for a system with:

- Light damping
- Heavy damping
- Critical damping

10. Define the terr

11. Explain the difference be oscillation.

Gravitational fie

Gravitational fields

1. Give the definitions of a uniform field and a radial field and describe how these relate to gravitational fields.

2. a) Sketch a radial gravitational field around a planet, indicating the direction of the field lines.

b) Explain what a gravitational field line indicates.

Gravitational field strength

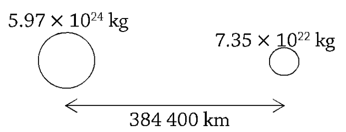
3. Every object on Earth feels a force of attraction directed towards the centre of Earth due to Earth's gravitational field.

Earth has mass 5.97×10^{24} kg and a radius of 6371 km.

Show that the gravitational field strength at the surface of Earth is 9.81 N kg^{-1}.

Newton's law of gravitation

4. The sketch below shows the separation of Earth and the Moon.



Calculate the force of gravitation between Earth and the Moon.

Kepler's laws

5. State Kepler's three laws of planetary motion.

Escape velocity

6. Determine the escape velocity needed for any object to escape Earth's gravitational field.
Earth has mass 5.97×10^{24} kg and a radius of 6371 km.

Geostationary satellites

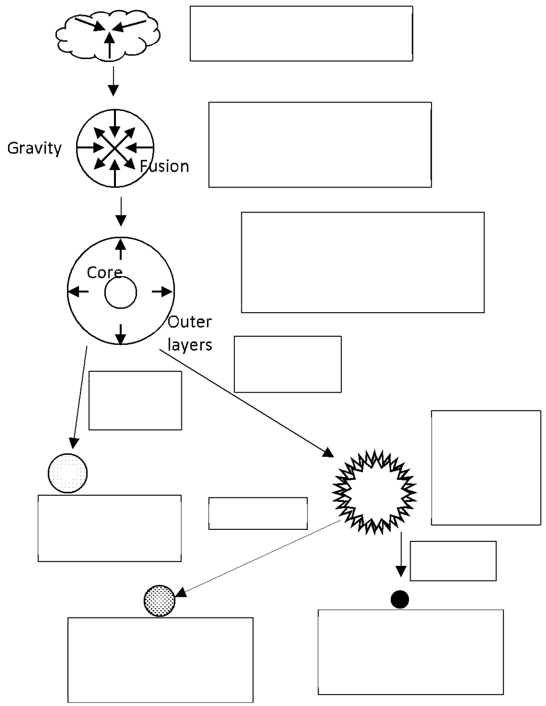
8. Using Kepler's third law, show that the period of a geostationary satellite is roughly 24 hours.
The orbital radius of a geostationary satellite is 35,786 km.

7. Derive Kepler's third from the centripetal forces acting on the s

Stars

Life cycle of a star

1. Complete the diagram below by adding a description for each stage of the life cycle of a star.



2. Describe the main characteristics of:

a) A white dwarf

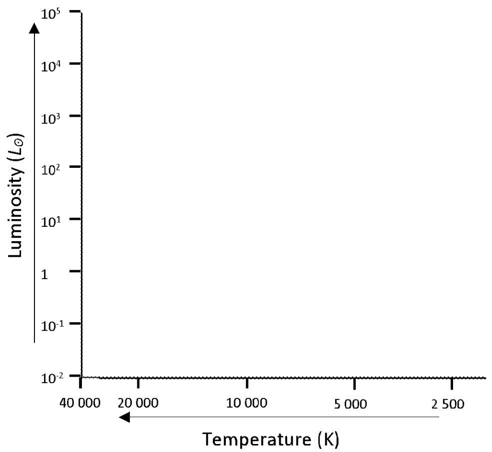
b) A neutron star

c) A black hole

4. A photon excites an electron from hydrogen's first excited state at -3.4 eV, to its third excited state, -0.9 eV.
Calculate the wavelength of the photon.

The Hertzsprung–Russell diagram

5. Complete the Hertzsprung–Russell diagram below, and add the path a sunlike star takes during its lifetime.



6. Describe the main features of the following types of star.

a) Brown dwarf

b) Red giant star

c) Main-sequence star

Cosmology

Astronomical distances

1. Convert:

a) 4.37 ly to m (distance to Alpha Centauri – nearest star to the Sun)

b) 779 km to AU (distance between the Sun and Jupiter)

c) 30 kpc to AU (diameter of the Milky Way)

d) 2.53×10^6 ly to pc (distance to Andromeda – nearest galaxy to the Milky Way)

2. Wolf 359 appears to travel 0.415 arcseconds over the course of a year.
Calculate the distance to Wolf 359 in light years.

3. Describe the cosmological principle.

4. The Sombrero Galaxy has a red shift of 0.003416. The Fraunhofer H_α line observed from the Sombrero Galaxy has a wavelength of 435.530 nm.

a) Calculate the original wavelength of the Fraunhofer H_α line.

b) Calculate the recessional velocity of the Sombrero Galaxy.

Red shift

5. The Whirlpool Galaxy sl
Calculate the distance t

6. Show how Hubble's lav
Use $H_0 \approx 70$ km s^{-1} Mp

7. Describe and explair

Capacitors

Capacitance

1. Define the term 'capacitance'.

2. What is a capacitor?

3. Explain how charge is stored on a parallel plate capacitor.

4. A 5μF capacitor has 4 V applied across its plates.

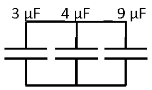
a) Calculate the total charge stored on the capacitor plates.

The potential difference applied to the plates is increased.

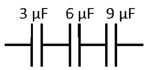
b) Sketch a graph of how the charge stored on the plates will change as the potential difference applied to the plates is changed.

5. Calculate the total capacitance of the following combinations of capacitor.

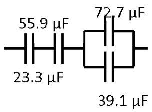
a)



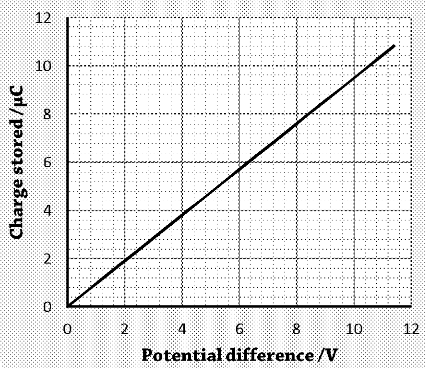
b)



c)



Energy stored by capacitor



6. The graph on the left shows the potential difference across a capacitor with varying charge stored by the capacitor.

Calculate the energy stored in the capacitor when there is a potential difference of 6.00 V across the capacitor.

7. Sketch the graphs of voltage

8. A 50 μF capacitor is being di

Initially the capacitor has 4.(

a) Calculate the charge acr

b) Calculate the time it wil discharge to half its init

9. A 500 μF capacitor is charge

Calculate the voltage across t

10. Draw a circuit w investigate the p

Electric fields

Electric field strength

Electric field strength in a radial field

1. Sketch the electric field pattern around an isolated positive charge.

2. Calculate the electric field strength generated by a 3.0 mC positive charge felt at a distance of 3.0 mm.

3. Define 'electric field strength'.

4. Explain what a field line represents in an electric field pattern.

5. Calculate the magnitude of the electric field strength felt by +2.10 mC charge that experiences a 50.0 mN force.

Electric field strength in a uniform field

6. Two parallel plates, which are separated by 0.0300 m, are connected to a power source and have a potential difference of 5.00 V between them.

   a) Sketch the electric field pattern between the two plates.

   b) Calculate the magnitude of the force exerted on a +1.10 mC charge positioned in between the two plates.

Coulomb's law

7. a) Describe what will happen to the force exerted on two charged objects
as the separation between them increases.

   b) Explain what will happen to the value of the force in (a) if the separation is increased to twice its original value.

Electric and gravitational fields

8. Fill in the missing values in the table below.

	Gravitational	Electros
Source of force field		Charge
Force	Inverse square law relationship with respect to distance between masses $F = \frac{GMm}{r^2}$	
Field strength		Force per unit
Potential in radial field	Always less than zero	

9.

10

12

Electromagneti

Magnetic flux density

1. Define 'magnetic flux density'.

2. A 0.3 m wire is carrying 0.6 A of current.

It is placed perpendicular to a 3.2 T magnetic field coming out of the page, as seen to the right.

a) Calculate the magnitude of the force exerted on the wire.

b) Determine the direction of motion of the wire when it is placed in the magnetic field.

3. A wire is at an angle to a 82 mT magnetic field. The wire carries a 510 mA current, and 15 cm of the wire sits in the magnetic field. The wire experiences a force of 3.8 mN. Calculate the angle between the wire and the magnetic field.

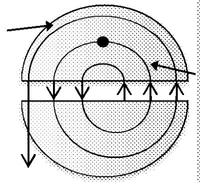
Moving charges in a magnetic field

4. A -3.0 mC charge is moving to the right at 1.6×10^4 m s^{-1} perpendicular to a 1.2 T magnetic field moving into the page.

a) Sketch the direction of the force exerted by the magnetic field on the moving charge.

b) Calculate the magnitude of the force exerted on the charge.

5. A cyclotron is used in medical physics to acce



a) State the direction of the magnetic field path shown is for a positive particle.

b) A particle accelerator operates with a 0.1

Calculate the radius of the path taken by at a speed of 2.5×10^7 m s^{-1}.

6. State Lenz's law.

7. Calculate the magnitude of the emf induced i sectional area of 0.070 m^2 and 50 turns that i field with magnetic flux density 1.3 T over 10

Magnetic flux and magnetic flux

8. A rectangular coil with dimensions 5.0 cm × 10 cm is placed perpendic to a 0.60 T magnetic field.

The coil consists of 10 turns of wire.

a) Calculate the magnetic flux of the coil.

b) Calculate the magnetic flux linkage through the coil.

c) Explain how the magnetic flux linkage would alter if the coil was rotated relative to the magnetic field.

Nuclei

Rutherford scattering

1. What was J J Thomson's plum pudding model?

2. Explain why the scientific community ceased to use J J Thomson's model.

3. Sketch the apparatus used by Rutherford in his scattering experiment and explain what each piece of apparatus was intended for.

4. Why did Rutherford deduce that the majority of a nucleus's mass is concentrated in a small region at its centre?

5. Sketch diagrams of J J Thomson's and Rutherford's nuclear models to explain the differences in the models.

Constituents of an atom

Simple model of an atom

6. Sketch and label the simple model of the atom.

Nuclide notation

8. State the number of protons and neutrons in the following nuclei:

   a) $^{238}_{92}U$

   b) $^{4}_{2}He$

9. Give two examples of isotopes of the same element in nuclide form.

Charge and mass of constituent parts

7. Fill in the table below. *Use the data booklet if you get stuck.*

	Charge	**Mass**
Electron		
Proton		
Neutron		

10. State the approximate

11. Sketch a graph of inter
diffraction for an elect

Constant densit

13. a) Show that the dens
approximately con

b) Calculate the value
Use $R_0 = 1.25$ fm.

Stable and un

15. Define the terms:

'strong nuclear force'

'unstable nucleus'

17. Sketch the strength of
separation.

Particles

Particles, antiparticles and photons

1. Comment on the relationship between charge and mass of a particle and its corresponding antiparticle.

3. Calculate the frequency of a photon of energy $E = 2.80 \times 10^{-18}$ J

6. Fill in the words missing from the bubbles in the mind map.

Antibaryons

3 antiquarks

Examples:

Properties of antiparticles

2. Complete the table below. ***Use the data booklet if you get stuck.***

	Particle	Charge	Rest mass	Rest energy
Positron				
Antineutron				
Antiproton				
Antineutrino				

Pair production

4. Calculate the minimum energy of the photon required to create a proton–antiproton pair.

Annihilation

5. Calculate the minimum frequency of one of the photons produced when an electron and a positron meet.

Quarks and antiquarks

7. Define the term 'quarks'.

Quark composition

8 State the quark composition of:

a) a proton

b) an antineutron

c) K^+

d) π^0

Quarks

9. a) State three types of quark.

b) State the baryon number of the quarks from your answer to part (a).

c) State the charge of the antiquarks from your answer to (a).

Application of conservation laws

10. Comment on whether the followin are valid. Give reasons for your an

a) $\pi^- + p \to K^0 + \Lambda^0$ ($\Lambda^0 = ud$

b) $\mu^- \to e^+ + \overline{\nu_\mu} + \nu_e$

c) $\nu_e + n \to \overline{p} + e^+$

11. Complete the following decay/inter equations:

a) $\mu^- \to e^- + \overline{\nu_e} + ?$

b) $K^0 + p \to ? + \pi^+$

Radioactive de

Types of decay

1. Complete the following decay equations and comment on the type of decay represented:

$$^{42}_{?}K \rightarrow {}^{?}_{20}C + {}^{0}_{-1}e + ?$$

$$^{226}_{?}Ra \rightarrow {}^{222}_{86}Rn + {}^{?}_{2}He$$

3. The following decay equa

$$^{235}_{92}U + {}^{1}_{0}$$

Calculate the energy rele

$m_n = 1.0087$ u
$m_{Kr-90} = 89.9195$ u
1 u = 931.5 MeV

2. Fill in the missing boxes in the following table.

Type of radiation	Consists of	Range in air	Ionisation	Absorption (stopped by…)	Example of application
Alpha		<100 mm	Creates around 10^4 ions per cm in air		
			Creates around 100 ions per mm in air		Thickness measurements of aluminium foil
Gamma		Obeys inverse square law		Stopped by several cm of lead	

6.

Radioactive decay

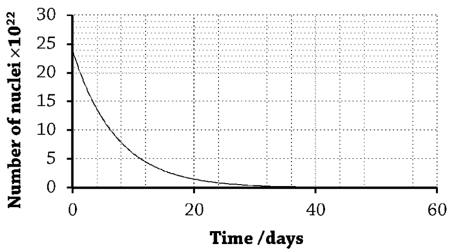
7. Explain what is meant by the statement 'radioactive decay is a random process'.

8. A sample of a radioactive isotope initially contains 4.70×10^{24} atoms. The decay constant for the isotope is 2.50×10^{-4} s^{-1}.

a) Calculate the remaining number of atoms of the isotope after 2,400 seconds.

b) Calculate the activity of the sample after this time.

c) What was the initial activity of the sample?

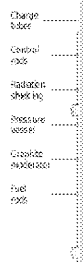


9. a) From the graph, determine the half-life of the radioactive isotope.

b) Calculate the decay constant of the isotope.

10. Explain how th

11. What is meant



INSPECTION COPY

Medical imagi

X-rays

1. Describe how X-rays are produced for use in medical imaging.

2. After passing through bone with a thickness of 3.50 cm, the intensity of an X-ray beam is reduced to 0.122 of its initial value.
The density of bone is 1.8 g cm^{-3}.
Calculate the mass attenuation coefficient of bone.

3. Describe the following mechanisms of X-ray attenuation, and state the regions in which they are dominant.

Simple scatter:

Photoelectric effect:

Compton effect:

Pair production:

4. Describe how CT scans are different from traditional X-rays, and the advantages and disadvantages of CT scans over traditional X-rays.

Radionuclides

5. Why is technecium-99m often used as a radionuclide tracer for use with gamma cameras?

6. With the use of a diagram, describe how gamma cameras collect and convert gamma rays from radionuclides into an image.

7. With the use of a diagram, describe how a photomultiplier tube works.

8. Describe how ultr

9. Describe the role
ultrasound.

11. Describe the adv
ultrasound over

14. Describe how the
ultrasound.

16. Describe how PE
interior of a patie

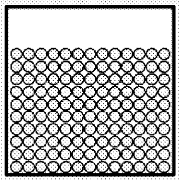
Thermal physi

Absolute zero

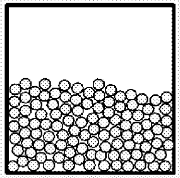
Thermal equilibrium

First la

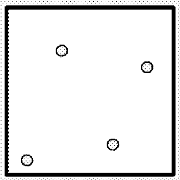
Solids, liquids, gases



Solids



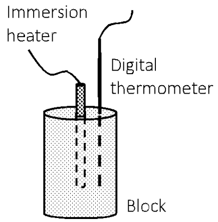
Liquids



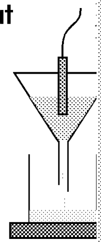
Gases

Brownian motion

Determining specific heat capacity



Determining specific latent heat



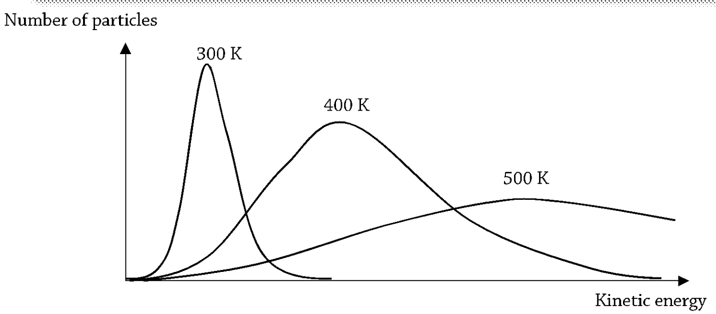
Ideal gases

Ideal gas laws

Molecular kinetic theory model

Mo

Kinetic theory equation



Average
molecul
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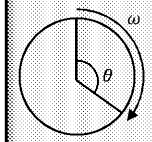
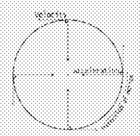
Internal
an ideal

Periodic motio

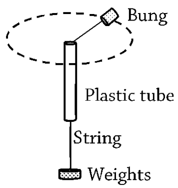
Circular motion

Angular quantities

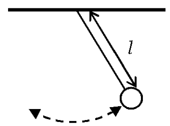


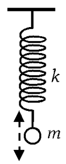


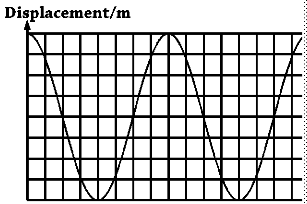
Investigating circular motion

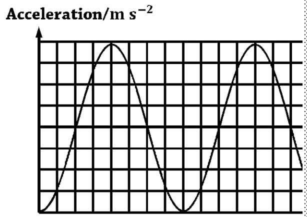


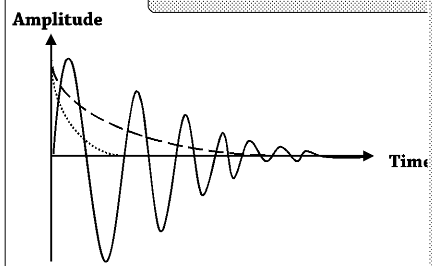
Investigating simple harmonic motion





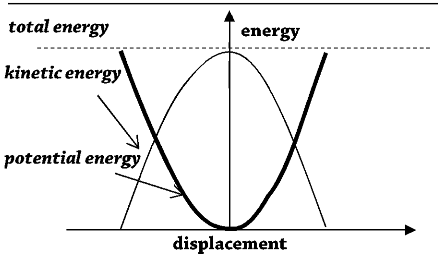






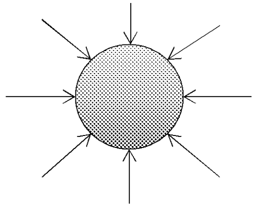
Damped oscillations

Energy–displacement graphs of SHM for free oscillations



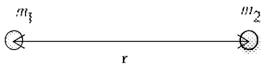
Gravitational fields

Gravitational fields



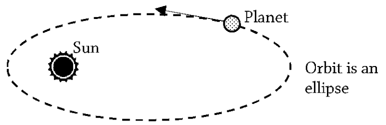
Gravitational field strength

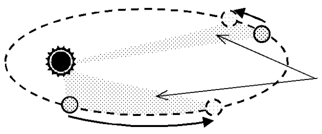
Newton's law of gravitation



$$F = \frac{Gm_1m_2}{r^2}$$

Kepler's laws of planetary motion





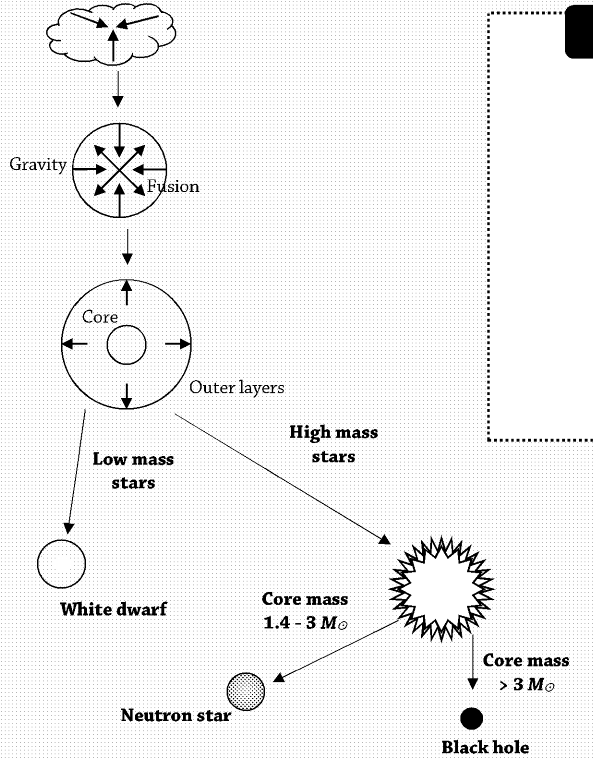
This shows the movement of the planet during two equal periods of time.
Planet travels faster when closer to the Sun, so that both shaded areas are of equal size.

Derivation of Kepler's third law

Geostationary satellites

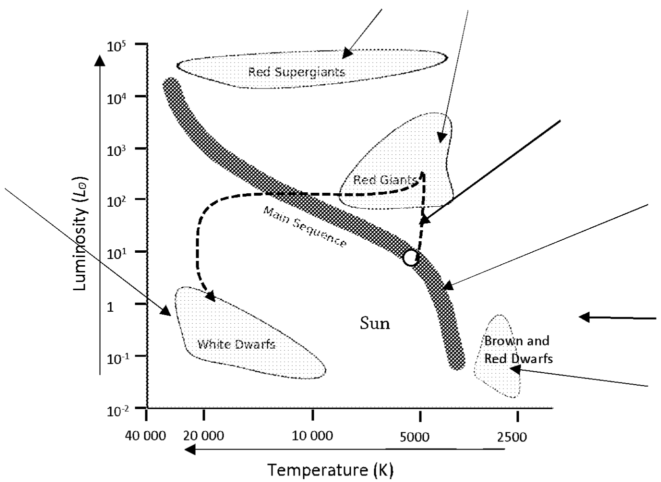
Stars

Life cycle of a star



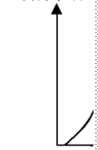
The deaths of stars

The Hertzsprung–Russell (HR) diagram



Absor

Black-b



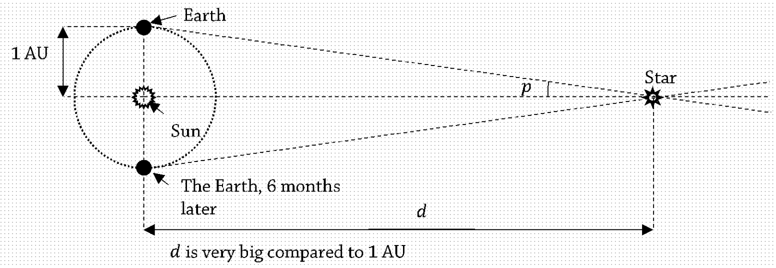
Wien

Exampl

Cosmology

Distances in astrophysics

Stellar parallax



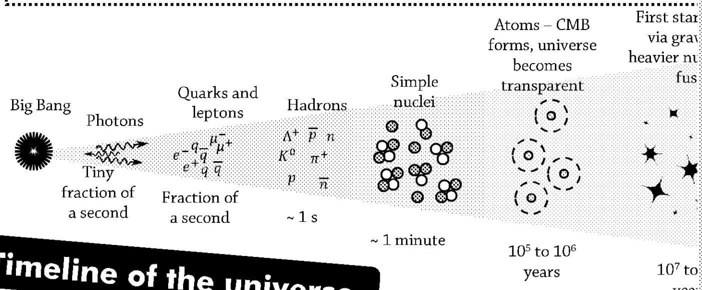
By

Cosmological principle

Doppler effect:

Hubble's law

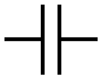
Hubble's law:



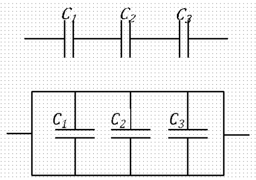
Timeline of the universe

Capacitors

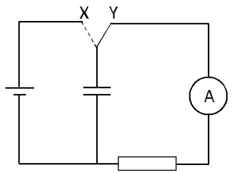
Capacitance



Combining capacitors



Measuring capacitance

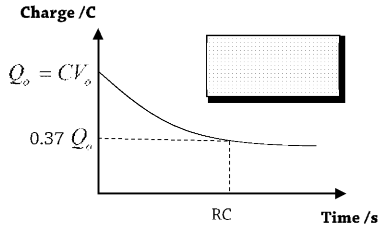


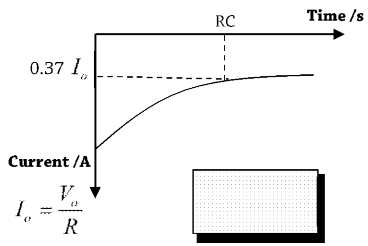
Energy stored by capacitor

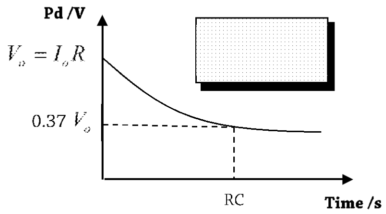
Energy stored:

Capacitor charge and d

Discharging a capaci





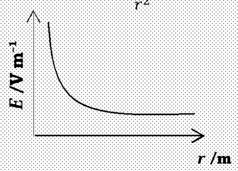


Voltage–charge g

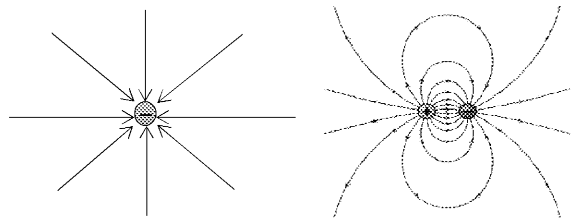
Electric field strength

E–r graph

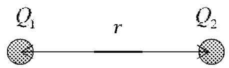
$E \propto \frac{1}{r^2}$

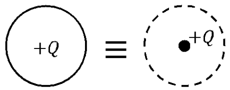


Radial fields



Coulomb's law



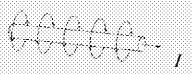


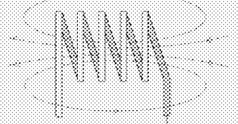
Work done to move charge

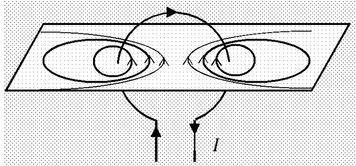
Electric and gravitational fields

Electromagneti

Magnetic flux density

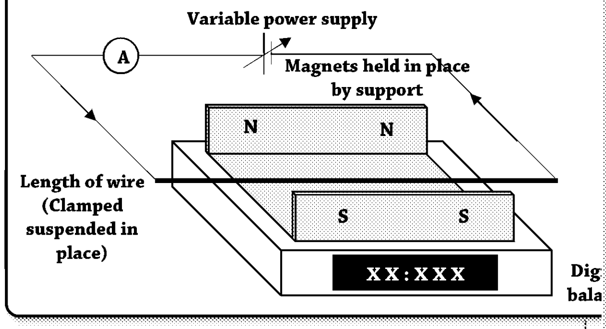




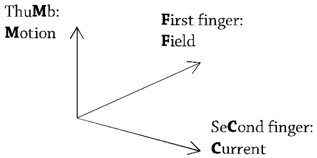


Force on a current-carrying wire in a magnetic field:

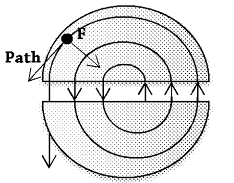
Investigation of force of a wire



Fleming's left-hand rule



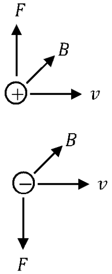
Charges moving in circular paths



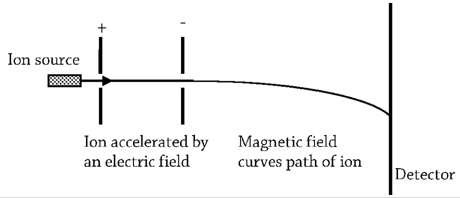
Magnetic field directed into the page for a positive particle

Moving charges in a magnetic field

Force on charged particles moving in a magnetic field:



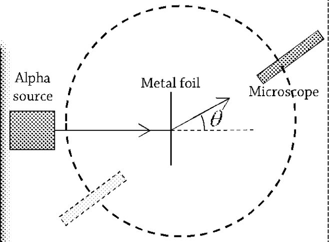
Velocity selector



Nuclei

Rutherford scattering

The experiment

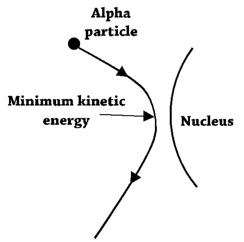


The results

The conclusions

Nuclear radius

Closest approach of alpha particles



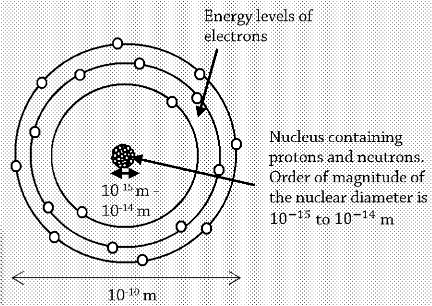
Strong nuclear

Unstable nucle

Prop

Constituents of an atom

Simple model of an atom



Charge and mass of constituent parts

	Charge/ C	Mass/ kg
Electron		
Proton		
Neutron		

Specific charge:

Isotope:

Nuclide notation

Particles

Particles and antiparticles

Photon energy:

$f = \frac{c}{\lambda}$

Properties of antiparticles

	Particle	Charge, q	Rest mass, m_0	Rest energy, E_0
Positron	Electron			0.511 MeV
Antineutron	Neutron	0 C		939.6 MeV
Antiproton	Proton			938 MeV
Antineutrino	Neutrino	0 C	0 kg	0 eV

Pair production

Annihilation

Quarks

	Symbol	Charge	Baryon number
Up			
Down			
Strange			

Quarks and antiquarks

Quarks:

Quark composition

Application of conservation laws

Conservation law
decays/interacti

INSPECTION COPY

Radioactive dec

Types of decay

Alpha decay:

Beta decay:

Gamma decay:

Background radiation

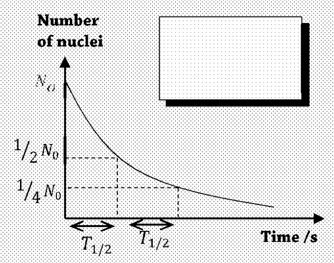
Type of radiation	Consists of	Range in air	Ionisation	Absorption	Applications
Alpha					
Beta					
Gamma					

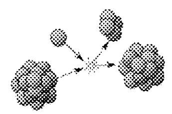
Radioactive decay

Decay probability:

Number of unstable nuclei:

Activity A:



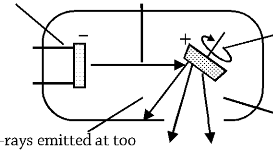


Induced fission

The thermal n

Medical imagi

X-rays



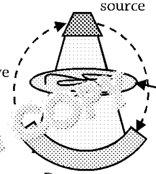
X-ray attenuation

Attenuation:

Attenuation

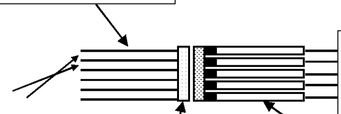
Detection

CT scans

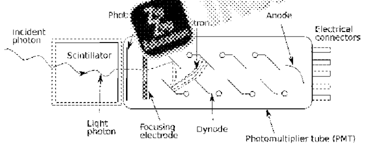


Gamma camera

Collimator



Scintillator



Ultrasound

Ultrasound scan

A-scans

B-scans

Uses

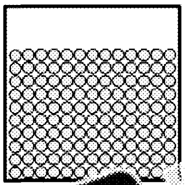
Mark Scheme

1: Thermal physics

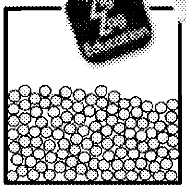
1. a) Absolute zero is the temperature at which all kinetic energy of a substance has energy is at a minimum.
   b) -273 °C, 0 K

2. a) 357.5 K
   b) -159 °C
   c) 3790 K

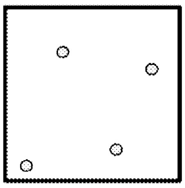
3.



Solids
There is small spacing between atoms and molecules, so the in solids have high densities.
Atoms and molecules in solids are very ordered and have fixed so solids have fixed shapes.



Liquids
The spacing between atoms and molecules is greater in liquids still quite close together. Because of this, the intermolecular fo strong, and liquids are less dense than solids.
Atoms and molecules in liquids are somewhat ordered and can't around each other, so liquids can flow.



Gases
Atoms and molecules in gases are very far apart, so they have v and have low densities.
Because the atoms and molecules in gases are very far apart, th molecules are free to move around.

4. Brownian motion describes the erratic motion of a small particle in a fluid.
The molecules in the fluid move randomly and hit into the particle, making the part
This can be seen in smoke particles suspended in air – rather than remaining statio they appear to bounce around.

5.
- Place immersion heater and digital thermometer in block or beaker of substanc
- Heat block and record the energy transferred using the power rating of the he Can measure power using ammeter and voltmeter.
- Measure temperature of block at regular intervals
- Plot energy transferred against temperature change
- Gradient is *mc*

6.
- Place immersion heater in a funnel filled with ice
- Heat ice, determining energy from the power of the heater
- At regular intervals, measure the mass of the water in the beaker
- Compare mass to a control funnel which is unheated. The mass of the water f the mass of the melted
- Plot energy transferred against mass of melted water
- Gradient is [illegible]

7. The sum of the randomly distributed kinetic energies and potential energies of par

8. The internal energy will have increased as the temperature has increased.

$\Delta U = Q + W$

$\Delta U = 1030 - 480$

$\Delta U = 550$ J

9. The change of internal energy of an object is equal to the total energy transfer due t

10. a) $Q = mc\Delta\theta$

$Q = 1.3 \times 2090 \times 5$

$Q = 13600$ J

b) The temperature remains constant as the ice goes under a change of state.

c) $Q = mL$

$Q = 1.3 \times 3.36 \times 10^5$

$Q = 437000$ J

d) The energy of the molecules increase and they vibrate enough to overcome the (ice) therefore changes into a liquid (water).

2: Ideal gases

1. The molar mass is the mass of one mole of ... bs...e (in kg mol^{-1}), whereas the m molecule in atomic mass units (u)

2. $pV = nRT$

$n = \frac{pV}{RT}$

$n = \frac{15\,200\,000 \times 6.5}{8.31 \times (20 + 273)}$

$n = 40\,600$

3. $W = p\Delta V$

$V_{initial} = V_{final} + \frac{W}{p} = 48 \times 10^{-6} + \frac{0.34}{950}$

$V_{initial} = 410 \times 10^{-6}$ m^3 = 410 cm^3

4. a) Doubles (using $\frac{p}{T} = constant$)

b) $\frac{V}{T} = constant$

$\frac{V_1}{T_1} = \frac{V_2}{T_2}$

$T_2 = \frac{T_1 V_2}{V_1} = \frac{300 \times 1.1}{1.4}$

$T_2 = 240$ K

c) $pV = constant$

$p_1 V_1 = p_2 V_2$

$V_2 = \frac{p_1 V_1}{p_2} = \frac{1.12 \times 10^3 \times 5.12 \times 10^{-6}}{1.55 \times 10^3}$

$V_2 = 3.69 \times 10^{-6}$ m^3 = 3.70 cm^3

5. Use a set-up using a piston attached to a pressure gauge. Ens...e piston is free to m
Heat the set-up with a Bunsen burner.
Measure change in height of piston to calcula...e v...lum...
Check pressure gauge to ensure it is co...st..., ...f not, adjust volume.
Plot volume against temper...e ...be a straight-line graph with gradient p.

6. **The pr... la...** ...gas in a container with a fixed volume, as the **temperatu** average... ...f the molecules increases and, therefore, the molecules collide with t more of... ...his increases the force exerted on the container walls and, therefore, t

Boyle's law: If the **volume** of the container of gas is decreased then the gas molec between collisions with the container wall. This results in there being more collisio wall and, therefore, the force exerted is increased and, therefore, so is the **pressure**.

Charles' law: As the **temperature** is increased on a gas, the average speed of the m the molecules collide with the sides of the container harder and more often. If the v the greater force on the walls of the container results in the walls of the container e volume.

7. a) $E_k = \frac{3}{2}kT$

$E_k = \frac{3}{2} \times 1.38 \times 10^{-23} \times (10 + 273)$

$E_k = 5.86 \times 10^{-21}$ J

b) $E_k = \frac{1}{2}mc_{rms}^2$

$c_{rms} = \sqrt{\frac{2 \times 5.86 \times 10^{-21}}{0.004 \div (6.02 \times 10^{23})}}$

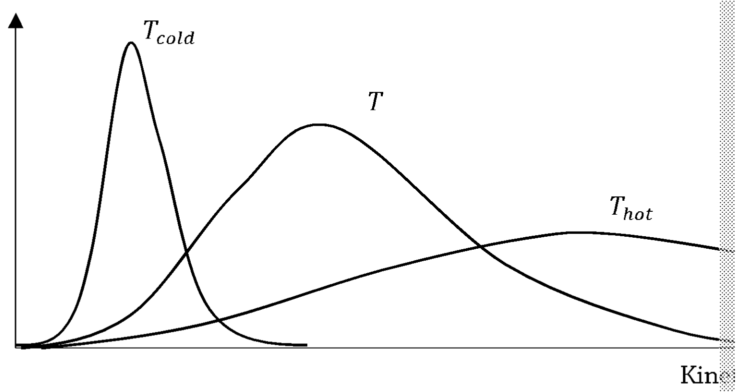
$c_{rms} = 1330$ m s^{-1}

c) $E_{k,total} = N_A \times n \times E_k$

$E_{k,total} = 6.02 \times 10^{23} \times 5 \times 5.8$ [illegible]

$E_{k,total} = 17\,60$ [illegible]

8. Numb [illegible] articles



9. $\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$

$pV = NkT$

$kT = \frac{pV}{N}$

$\frac{1}{2}m\overline{c^2} = \frac{3}{2}\frac{pV}{N}$

$p = \frac{1}{3}\frac{Nm}{V}\overline{c^2}$

3: Periodic motion

1. A centripetal force provides a force/acceleration t[illegible] d[illegible] e centre of the circular p

2. $\omega = 2\pi f$

$\omega = 2\pi \times 20$

$\omega = 1$ [illegible] s

3. a) $v = \frac{circumference}{time\ for\ one\ rotation}$

$v = \frac{2\pi r}{T}$

$v = \frac{2 \times \pi \times 42\,157 \times 10^3}{24 \times 60 \times 60}$

$v = 3065.7$ m s^{-1}

b) Due to the centripetal force exerted on the satellite due to Earth's gravitational

c) $a = \frac{v^2}{r}$

$a = \frac{3605.7^2}{42157 \times 10^3}$

$a = 0.223$ m s^{-2}

4. Simple harmonic motion refers to an oscillating motion where the acceleration of t[illegible] the displacement from the equilibrium position and opposite in direction.

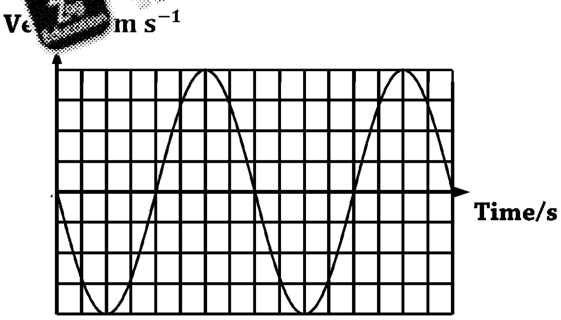
5. $a = -\omega^2 x$

$a = -(1.2)^2 \times 0.8$

$a = 1.2$ rad s^{-2}

6. a)
- 0.5 m
- $\frac{500}{2} = 250$ s

b)



c) $v_{max} = \omega A$

$v_{max} = \frac{2\pi}{T} A$

$v_{max} = \frac{2\pi}{250} \times 0.5$

$v_{max} = 0.01$ m s^{-1}

d) $a_{max} = \omega^2 A$

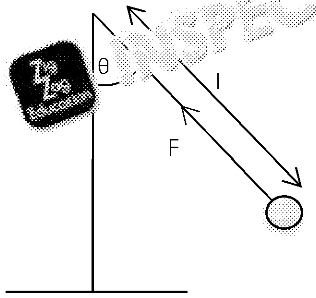
$a_{max} = \left(\frac{2\pi}{T}\right)^2 A$

$a_{max} = \left(\frac{2\pi}{250}\right)^2 \times 0.5$

$a_{max} = 3.2 \times 10^{-4}$ m s^{-2}

7. a) The acceleration is directly [illegible] to the displacement from the equilibri[illegible]

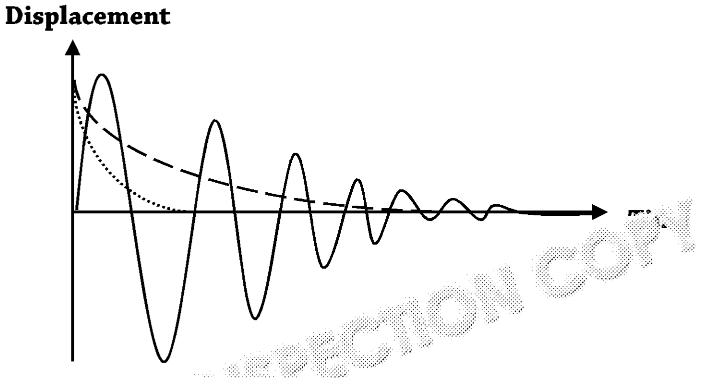
b)



c) The kinetic energy is maximum at the equilibrium position and zero at the am[illegible] potential energy is maximum at the amplitude position and zero at the equilib[illegible]

8. Oscillations in which energy and amplitude of oscillations are lost to the damping o

9. Heavy dashed line: Heavy damping
Dotted line: Critical damping
Solid line: Light damping

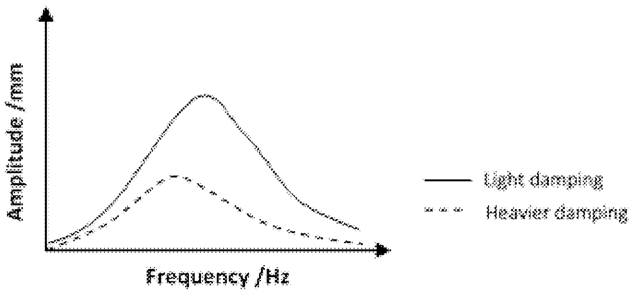


10. Resona[...]rs [...] the situation in which the driving force of the oscillation is in p
oscillati[...]em and the amplitude of oscillation increases.

11. **Free oscillation:** an oscillation of a body or system that is moving with its natural f
external influence.

Forced oscillation: an oscillation of a body or system that is initiated by an extern

12.

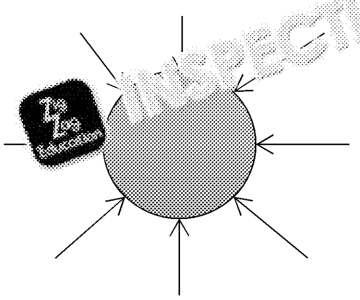


4: Gravitational fields

1. **Radial field:** A field that is circular and acts towards a central point. Gravitational f

Uniform field: A field that has no variation. Gravitational [...]ds are approximated
planets.

2. a)



b) A gravitational field line illustrates the path a smaller mass takes towards a lar

3. $g = \dfrac{GM}{r^2}$

$$g = \frac{6.67\times10^{-11}\times5.97\times10^{24}}{(6371000)^2}$$

$$g = 9.81\ \text{N kg}^{-1}$$

4. $F = \dfrac{GMm}{r^2}$

$$F = \frac{6.67\times10^{-11}\times5.97\times10^{24}\times7.35\times10^{22}}{(384\,400\,000)^2}$$

$$F = 1.98\times10^{20}\ \text{N}$$

5.
   1. A planet orbits the Sun in an elliptical orbit, with the Sun at one of the focal po
   2. The area swept out by the line connecting the Sun and a planet sweeps out a cons
   3. The period of a planet's orbit squared is proportional to the average radius of t

$$T^2 \propto r^3$$

$$T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$$

6. $v = \sqrt{2gr}$

$$v = \sqrt{2\times9.8\times6\ 371\ 000}$$

$$v = 1.12\times10^4\ \text{m s}^{-1}$$

7. $F_{centripetal} = F_{gravitation}$

$$\frac{mv^2}{r} = \frac{GMm}{r^2}$$

$$v^2 = \frac{GM}{r}$$

$$v = \frac{2\pi r}{T}$$

$$\frac{(2\pi r)^2}{T^2} = \frac{GM}{r}$$

$$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$$

$$\frac{GM}{4\pi^2} = \text{constant} = \text{same for all planets}$$

$$T^2 \propto r^3$$

8. $\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$

$T^2 = \frac{4\pi^2 r^3}{GM}$

$T^2 = \frac{4\pi^2 (6\ 371\ 000 + 35\ 786\ 000)^3}{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}$

$T^2 = 7\ 427\ 944\ 755$

$T = 86\ 185.53$ seconds

$T = \frac{86\ 185.53}{60 \times 60}$

$T = 2$[illegible]rs

9. **Gravitational potential energy** (E_P): the energy possessed by an object due to i

Gravitational potential (V): the work required to move an object from infinity t

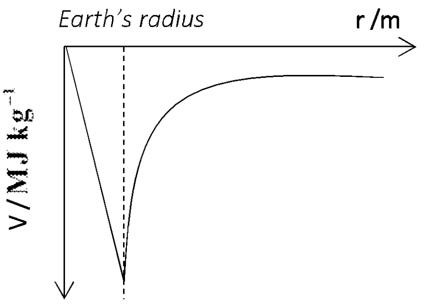
10. Zero

11. $V = \frac{-GM}{r}$

$V = \frac{-6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{(35\ 786\ 000 + 6\ 371\ 000)}$

$V = -9.45 \times 10^6\ \text{J kg}^{-1}$

12. a)



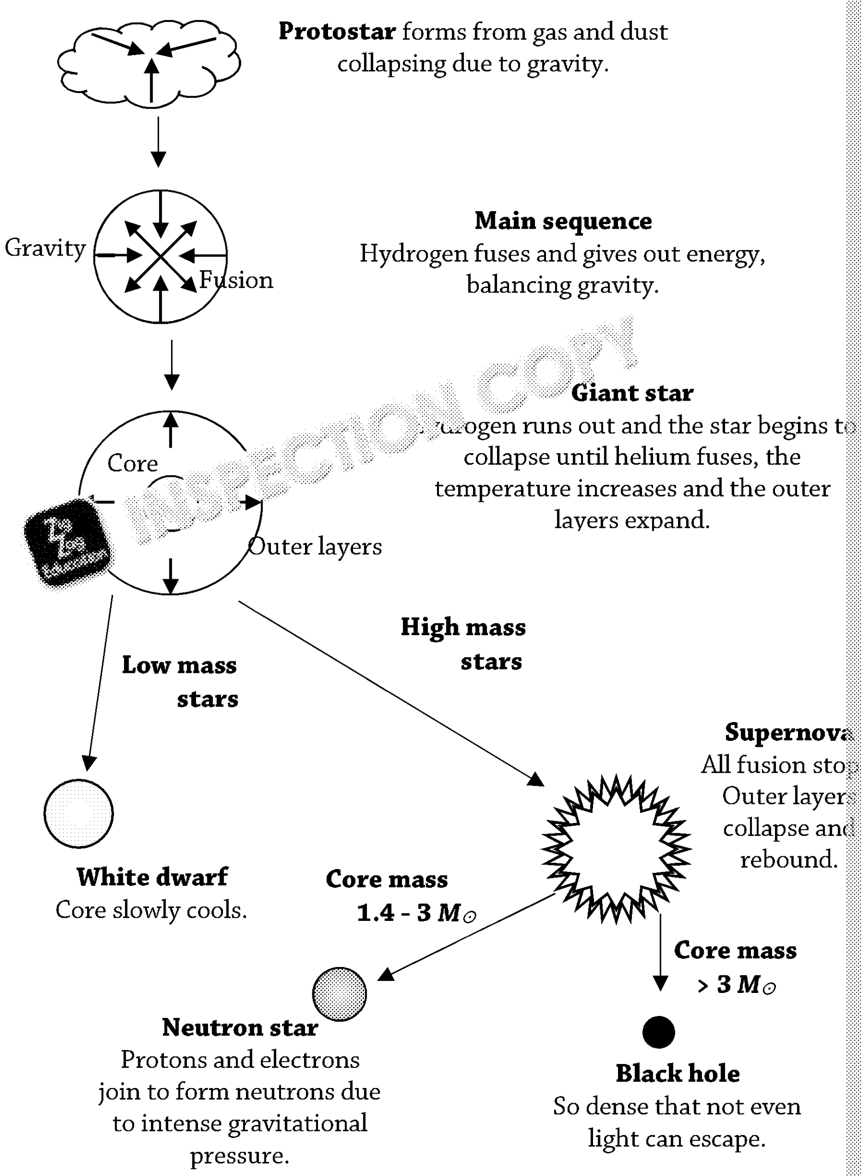
b) From the gradient of the graph.

13. Equipotentials are surfaces of const[illegible] po[illegible]l.

14. No work would be d[illegible] since $\Delta W = m\Delta V$ and $\Delta V = 0$ when travelling along t

5: Stars

1.



2. a) A white dwarfs is the leftover core of a star, which no longer undergoes fusion. White dwarfs gradually cool and radiate all their heat, and become black dwarfs

b) If the core left over after a supernova has a mass of 1.4× to 3.0× solar masses, i… radius of about 10 km.

In the core of a neutron star, gravi… gr… that protons and electrons join

c) If the core left ov… than 3× solar masses, it forms a black hole. A bla… nothi… ca… …ot even light.
T… a… …nd a black hole from which nothing can escape is called the even…

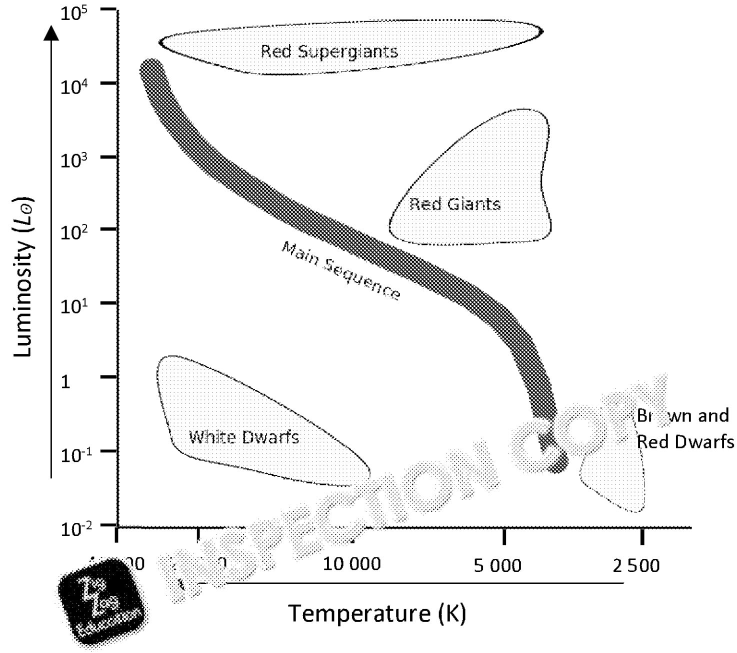
3. Photons from stars are absorbed by atoms in the outer layers of stars. This causes e… These energy levels are specific to the atom, so each atom absorbs specific waveleng… missing wavelengths in a spectrum can be used to identify the composition of a sta…

4. $E = \frac{hc}{\lambda}$

$\lambda = \frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{(-0.9 + 3.4) \times 1.60 \times 10^{-19}}$

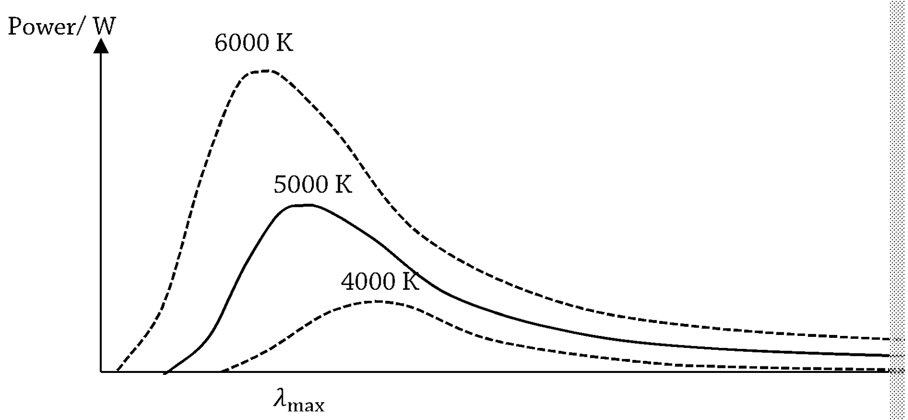
$\lambda = 497$ nm

5.



6. a) Brown dwarfs are starlike objects with masses too low to fuse hydrogen.
   b) Giant stars are large and bright.
   Red giants fuse helium in their cores after they run out of hydrogen to fuse.
   c) All stars spend most of their lives in the main sequence.
   This is when they fuse hydrogen into helium.
   Most stars, including the Sun, are on the main sequence.

7.



8. $\lambda_{max} T = 2.9 \times 10^{-3}$ m K

$\lambda_{max} = \frac{2.9 \times 10^{-3}}{T} = \frac{2.9 \times 10^{-3}}{5344}$

$\lambda_{max} = 5.4 \times 10^{-7}$ m (= 540 nm)

9. $P = 4\pi r^2 \sigma T^4$

$T = \left(\frac{P}{4\pi r^2 \sigma}\right)^{\frac{1}{4}} = \left(\frac{3\ [illegible]\ 10^{3[illegible]}}{5.6[illegible]\ 0\ [illegible] \times [illegible] \times (2.00 \times 10^{10})^2}\right)^{\frac{1}{4}}$

$T = 5.84$ [illegible] 0^4 [illegible]

10. $T = \frac{2.9 \times [illegible]}{\lambda} = \frac{2.9 \times 10^{-3}}{115 \times 10^{-9}}$

$T = 2.52 \times 10^4$ K

$4\pi r^2 = \frac{P}{\sigma T^4}$

$r = \sqrt{\frac{P}{4\pi r^2 \sigma T^4}} = \sqrt{\frac{2.15 \times 10^{25}}{4\pi \times 5.67 \times 10^{-8} \times (2.52 \times 10^4)^4}}$

$r = 8.65 \times 10^6$ m

6: Cosmology

1. a) $4.37\ \text{ly} = 4.37 \times 9.46 \times 10^{15} = 4.13 \times 10^{16}$ m
   b) $779 \times 10^6\ \text{km} = \frac{779 \times 9}{1.50 \times 10^{11}} = 5.19$ AU
   c) $30\ \text{kpc} = 30 \times 10^3 \times 2.06 \times 10^5 = 6.2 \times 10^9$ AU
   d) $2.53 \times 10^6\ \text{ly} = \frac{2.53 \times 10^6}{3.26} = 7.76 \times 10^5$ pc

2. $p = \frac{1}{d}$
   $d = \frac{1}{p}$
   $d = \frac{1}{0.415}$
   $d = 2.409$ pc
   $d = 2.409 \times 3.26 = 7.86$ ly

3. The cosmological principle st[illegible]:
   - The universe i[illegible] **[illegible]ous** – its density is relatively uniform on a large scale
   - The [illegible]se [illegible]**tropic** – it looks the same when looking in any direction and [illegible]
   - The [illegible] physics are **universal**.

4. 1. a) $z = \frac{\Delta\lambda}{\lambda} = \frac{\lambda_{observed - \lambda}}{\lambda}$
   $\lambda = \frac{\lambda_{observed}}{1+z} = \frac{435.530 \times 10^{-9}}{1 + 0.003416}$
   $\lambda = 434.047$ nm
   b) $z = \frac{v}{c}$
   $v = zc = 0.003416 \times 3.00 \times 10^8$
   $v = 1.02 \times 10^6$ m s^{-1}

5. $v = \frac{\Delta f}{f} \times c = \frac{6.9747 \times 10^{14} - 6.9639 \times 10^{14}}{9.9639 \times 10^{14}} \times 3.00 \times 10^8$
   $v = 4.652 \times 10^5$ m s^{-1}

   $d = \frac{v}{H} \approx \frac{4.652 \times 10^5}{70 \times 10^3}$
   $d \approx 6.65$ Mpc = 21.7×10^{17} ly

6. Assume H_0 is constant
   d is the distance the furthest galaxies have been able to move away from the initial [illegible]
   v is the velocity at whichthese galaxies have moved away
   This gives

$$t_{Universe} = \frac{d}{v} = \frac{1}{H_0}$$

   $t_{universe} = \frac{1}{2.27 \times 10^{-18}} = 4.4 \times 10^{17}$ s = 13.9 billion years

7. - **Red shift of distant galaxies**
     - Implies all galaxies are expan[illegible] [illegible]ngle point
   - **Cosmic microwave back[illegible] [illegible]B)**
     - Radiation le[illegible] the Big Bang
     - [illegible] over time and is now equivalent to ~ 2.7 K
   - **A[illegible]ce of hydrogen and helium in the universe**
     - [illegible]er in the universe is about 74 % hydrogen, 24 % helium and trace a[illegible]
     - A short, intense period of high energy (such as the Big Bang) would only [illegible]
     - All heavier elements have been produced in stars since then

7: Capacitors

1. **Capacitance** of a capacitor is defined as the charge stored per unit pd.

2. A **capacitor** is an electrical device that stores charge.

3. A **parallel plate capacitor** is comprised of two parallel conducting plates. If the pl source, then as electrons flow through the power source they are forced from the ne to one of the plates.

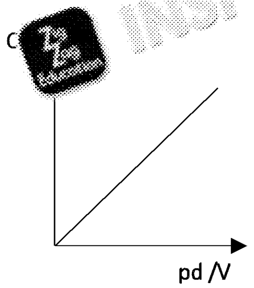
   Due to the interaction between like charges, an equal number of electrons leave the positive terminal of the power supply and the plate gains an equal but positive char

4. a) $Q = CV$

   $Q = 5\times10^{-6}\times4$

   $Q = 2\times10^{-5}$ C

   b) C



5. a) $C_T = C_1 + C_2 + C_3$

   $C_T = 3 + 4 + 9$

   $C_T = 16\ \mu\text{F}$

   b) $\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$

   $\frac{1}{C_T} = \frac{1}{3} + \frac{1}{6} + \frac{1}{9} = 0.611\ \mu\text{F}^{-1}$

   $C_T = 1.6\ \mu\text{F}$

   c) $\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3 + C_4}$

   $\frac{1}{C_T} = \frac{1}{55.9} + \frac{1}{23.3} + \frac{1}{72.7 + 39.1} = 0.06975\ \mu\text{F}^{-1}$

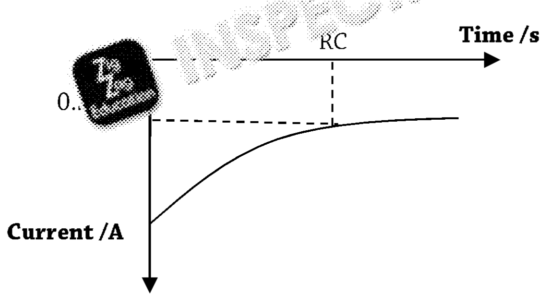
   $C_T = 14.3\ \mu\text{F}$

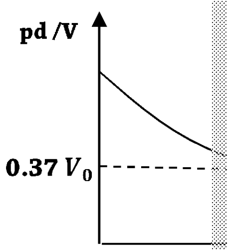
6. $E = \text{area under graph} = \frac{1}{2}QV$

   $E = \frac{1}{2}\times5.70\times6.00\times10^{-6}$

   $E = 1.70\times10^{-5}$ J

7.





8. a) $Q = 0.37Q_o$

$Q = 0.37 \times 4 \times 10^{-6}$

$Q = 1.5 \times 10^{-6}$ C

b) $t_{1/2} = 0.69RC$

$t_{1/2} = 0.69 \times 10 \times 50 \times 10^{-6}$

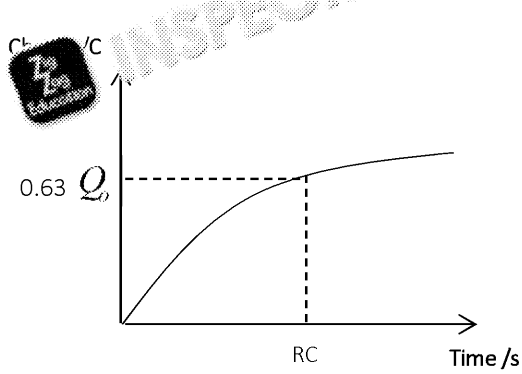
$t_{1/2} = 3.5 \times 10^{-4}$ s

c) $Q = Q_o e^{-\frac{t}{RC}}$

$Q = 4 \times 10^{-6} \times e^{-\frac{0.1 \times 10^{-3}}{10 \times 50 \times 10^{-6}}}$

$Q = 3.3 \times 10^{-6}$ C

d)

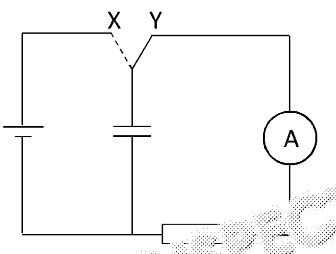


9. $V = V_o\left(1 - e^{-\frac{t}{RC}}\right)$

$V = 0.5 \times \left(1 - e^{-\frac{0.2 \times 10^{-3}}{12 \times 500 \times 10^{-6}}}\right)$

$V = 0.0164$ V

10.



11. $\frac{\Delta Q}{\Delta t} = -\frac{Q}{CR}$

$Q_0 = 28.3$ mC

$Q_1 = 28.3 \times 10^{-3} - \frac{(28.3 \times 10^{-3})}{44.0 \times 10^{-6} \times 15.5 \times 10^{3}} \times 0.1 = 0.02415$

$Q_2 = 0.02061$

$Q_3 = 0.01759$

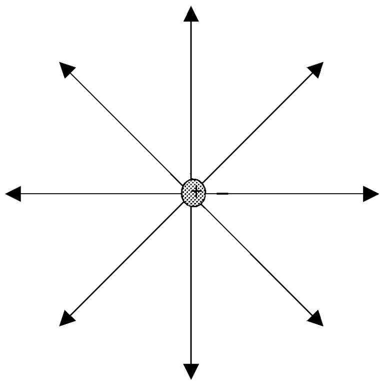
…

$Q_9 = 6.793 \times 10^{-3}$ C

$\mathbf{Q_{10} = 5.797\ mC}$

8: Electric fields

1.



2. $E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$

$E = \frac{1}{4\pi [illegible]}\frac{[illegible] 0^{-}}{[illegible]^{-3}}$ [illegible]

$E = 3.0 \times 10^{12}$ V m^{-1} (or N C^{-1})

3. Electric field strength is defined as the force per unit charge on a positive test charg

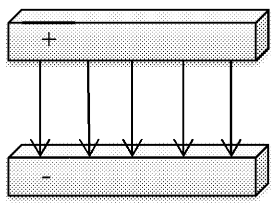
4. The direction of the force on a positive test charge placed in the electric field.

5. $E = \frac{F}{Q}$

$E = \frac{50.0 \times 10^{-3}}{2.10 \times 10^{-3}}$

$E = 23.8$ V m^{-1} (or N C^{-1})

6. a)



b) $\frac{F}{Q} = \frac{V}{d}$

$F = \frac{VQ}{d}$

$F = \frac{5 \times 1.1 \times 10^{-3}}{0.0[illegible]}$

$F = $ [illegible]83 N

7. a) The force between the charges will decrease.
   b) Since the force follows the inverse square law, the force will decrease to a quar

8.

	Gravitational	
Source of force field	Mass	
Force	Inverse square law relationship with respect to distance between masses $F = \frac{GMm}{r^2}$	Inverse squ[illegible]
Field strength	Force per unit mass	
Potential in radial field	Always less than zero	Sig[illegible]

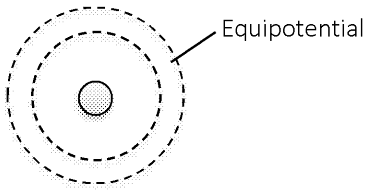
9. **Electric potential:** the work done per unit charge on [illegible] charge when it is m[illegible]

10. $\Delta W = Q\Delta V$

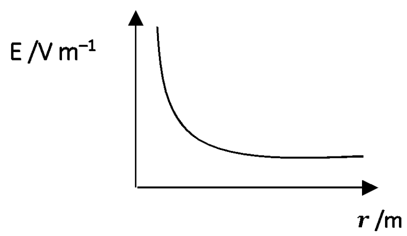
$\Delta W = 4.3\times10^{-6}\times12$

$\Delta W =$ [illegible]

11.



12. a)



b) The area enclosed by two points on the E–R graph.

13. **Dielectrics** are electrically insulating materials.

14. Capacitor 1, $C = \frac{A\varepsilon_0\varepsilon_r}{d}$

15. $C = \varepsilon_r C_o$

$C = 7\times42\times10^{-6}$

$C = 2.9\times10^{-4}$ F

16. a) $C = \frac{A\varepsilon_0\varepsilon_r}{d}$

$C = \frac{[illegible]3\times8.85\times10^{-12}\times2.3}{0.01}$

$C = 6.11\times10^{-11}$ F

b) The capacitance would be greater because capacitance is directly proportional [illegible] in a larger area.

9: Electromagnetism

1. **Magnetic flux density:** is magnetic field strength acting through a unit area.

2. a) $F = BIL$

   $F = 0.3 \times 0.6 \times 3.2$

   $F = 0.6\ \text{N}$

   b) To the left

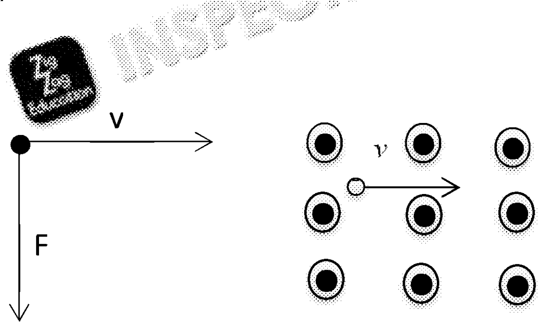
3. $F = BIL\sin\theta$

   $\theta = \sin^{-1}\frac{F}{BIL}$

   $\theta = \sin^{-1}\frac{3.8 \times 10^{-3}}{82 \times 10^{-3} \times 510 \times 10^{-3} \times \ldots}$

   $\theta = 37°$

4. a)



   b) $F = QvB$

   $F = -3 \times 10^{-3} \times 1.6 \times 10^{4} \times 1.2$

   $F = 58\ \text{N}$

5. a) Into page

   b) $r = \frac{mv}{QB}$

   $r = \frac{9.11 \times 10^{-31} \times 2.5 \times 10^{7}}{1.6 \times 10^{-19} \times 0.16}$

   $r = 8.9 \times 10^{-4}\ \text{m}$

6. **Lenz's law:** the direction of the induced current is always such that it is opposed t current.

7. $\varepsilon = N\frac{\Delta\phi}{\Delta t}$

   $\varepsilon = 50 \times \frac{1.3 \times 0.07\ldots}{1\ldots}$

   $\varepsilon = 0.\ldots$

8. a) $\phi = BA$

   $\phi = 0.6 \times 0.05 \times 0.1$

   $\phi = 3 \times 10^{-3}\ \text{Wb}$

b) $$magnetic\ flux\ linkage = BAN$$
$$magnetic\ flux\ linkage = 0.6 \times (0.05 \times 0.1) \times 10$$
$$magnetic\ flux\ linkage = 0.03\ \text{Wb}$$

c) The magnetic flux linkage would become $BAN\cos\theta$, where θ is the angle b
the cross-section of the coil.

9. $$\varepsilon = N\frac{\Delta\phi}{\Delta t}$$
$$\varepsilon = 50 \times \frac{1.3 \times 0.07}{10}$$
$$\varepsilon = 0.46\ \text{V}$$

10. a) $$\frac{N_s}{N_p} = \frac{V_s}{V_p}$$
$$V_s = V_p \times \frac{N_s}{N_p}$$
$$V_s = 25\ 000 \times \frac{11\ 000}{1000}$$
$$V_s = 275\ \text{kV}$$

b) The electricity can be transmitted at a low current which reduces the powe
transmit.

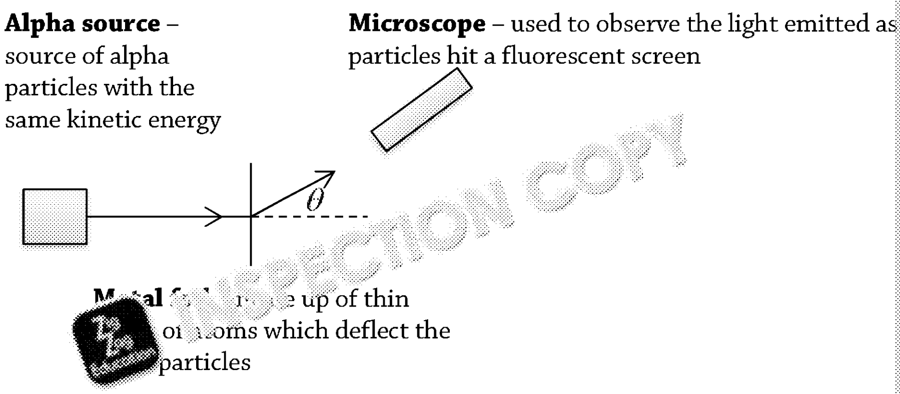
c)
- Resistance in the coils
- Eddy currents
- Work done to produce magnetic field

d) $$efficiency = \frac{I_s V_s}{I_p V_p} \times 100\ \%$$
$$efficiency = \frac{2.9 \times 275\ 000}{40 \times 25\ 000} \times 100\ \%$$
$$efficiency = 79.8\%$$

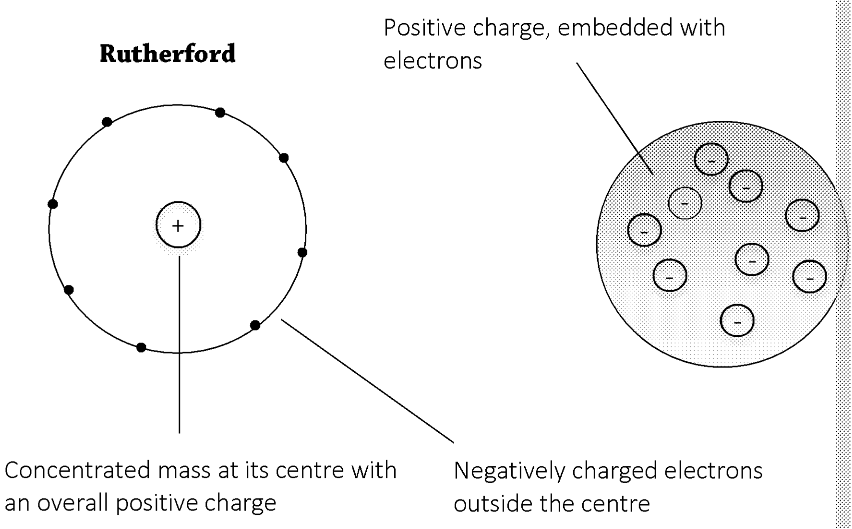
10: Nuclei

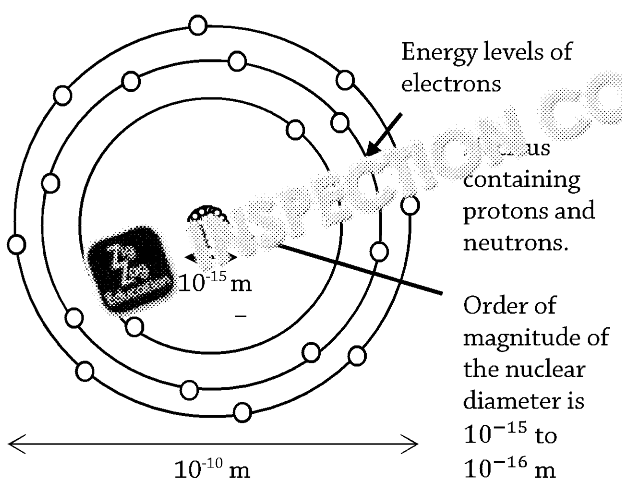
1. The plum pudding model suggested that an atom is a ball of positive charge that is e negatively charged. The positive charge balances the negative charge of the electron

2. Rutherford completed a scattering experiment, the finds of which contradicted J J T provided evidence that J J Thomson's model was inaccurate.

3. 

4. Most of the alpha particles that came into contact with the gold foil travelled right t the majority of the mass isn't distributed throughout the atom but in a very small r

5. 

6. 

7.

	Charge	Mass
Electron	-1.6×10^{-19} C	9.11×10^{-31} kg
Proton	$+1.6\times10^{-19}$ C	$1.67(3)\times10^{-27}$ kg
Neutron	0 C	$1.67(5)\times10^{-27}$ kg

8. a) Protons: 92
   Neutrons: 238 – 92 = 146
   b) Protons: 2
   Neutrons: 4 – 2 = 2

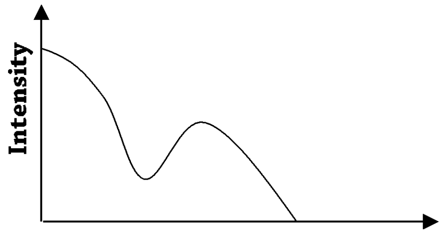
9. Any two nuclei of the same element that have the same proton number, e.g.

$${}^{A_1}_{Z_1}X;\ {}^{A_2}_{Z_2}X$$

where [illegible] and $A_1 \neq A_2$

10. $\sim 10^{-15}$ m

11.



12. Alpha particles are directed towards a nucleus. As the alpha particles approach the n[illegible] gain potential energy. The deflection of the alpha particles can be used to determin[illegible] particles using Coulomb's law.

13. a)

$$V = \frac{4}{3}\pi R^3$$

$$V = \frac{4}{3}\pi R_o{}^3 A$$

$$\rho = \frac{m}{V}$$

$$\rho = \frac{Au}{\frac{4}{3}\pi R_o{}^3 A}$$

$$\rho = \frac{u}{\frac{4}{3}\pi R_o{}^3}$$ [illegible]

b)

$$\rho = \frac{1.661\times10^{-27}}{\frac{4}{3}\pi(1.25\times10^{-15})^3}$$

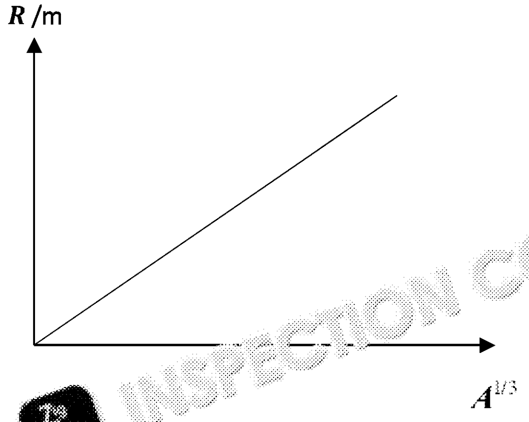
$$\rho = 2.03\times10^{17}\ \text{kg m}^{-3}$$

14. a) $R = r_o A^{1/3}$

$R = 1.25 \times 10^{-15} \times 12^{1/3}$

$R = 2.86 \times 10^{-15}$ m

b)

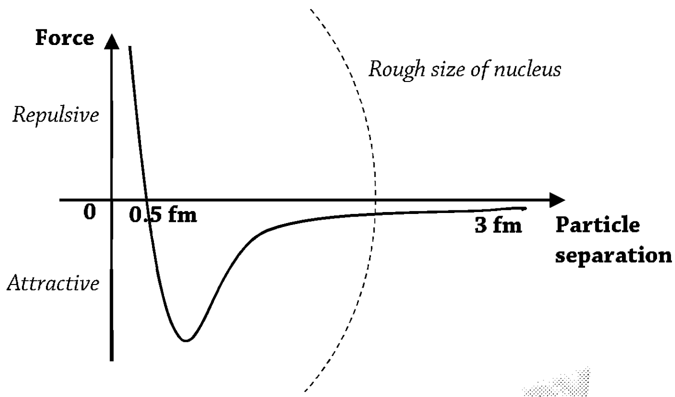


15. **Strong nuclear force:** the attractive force between nucleons, which binds them to

Unstable nucleus: a nucleus that has an imbalance of neutrons and protons, creat
strong nuclear forces to hold the nucleus together

16.
- The strong nuclear force compensates for the repulsive electrostatic force betw
- It has a range of 3–4 fm.
- It has the same effect between two protons as it does between a proton and ne
- It is an attractive force from 3–4 fm to 0.5 fm.
- It is a repulsive force at separation less than 0.5 fm.
- It is a repulsive force at this separation to ensure that neutrons and protons a

17.



11: Particles

1. The rest mass of an antiparticle is the same as the rest mass of its corresponding pa
The charge of an antiparticle is equal and opposite to that of its corresponding parti

2.

	Particle	Charge	Rest
Positron	**Electron**	$+1.6\times10^{-19}$ C	9.11×1
Antineutron	**Neutron**	0 C	$1.67(5)\times$
Antiproton	**Proton**	-1.6×10^{-19} C	$1.67(3)\times$
Antineutrino	**Neutrino**	[illegible] C	0

3. $E = hf$

$f = \frac{E}{h}$

$f = \frac{2.[illegible]}{6.63\times10^{-34}}$

$f = 4.22\times10^{15}$ Hz

4. *Energy of photon = Rest energy of proton + Rest energy of antiproton*

$hf_{\min} = 2E_o$

$2E_o = 2\times1.67\times10^{-27}\times(3\times10^8)^2$

$2E_o = 3.01\times10^{-10}$ J

$hf_{\min} = 3.01\times10^{-10}$ J

5. *Energy of positron + Energy of electron = Energy of two photons*

$2E_o = 2hf_{\min}$

$E_o = hf_{\min}$

$E_o = 9.11\times10^{-31}\times(3\times10^8)^2$

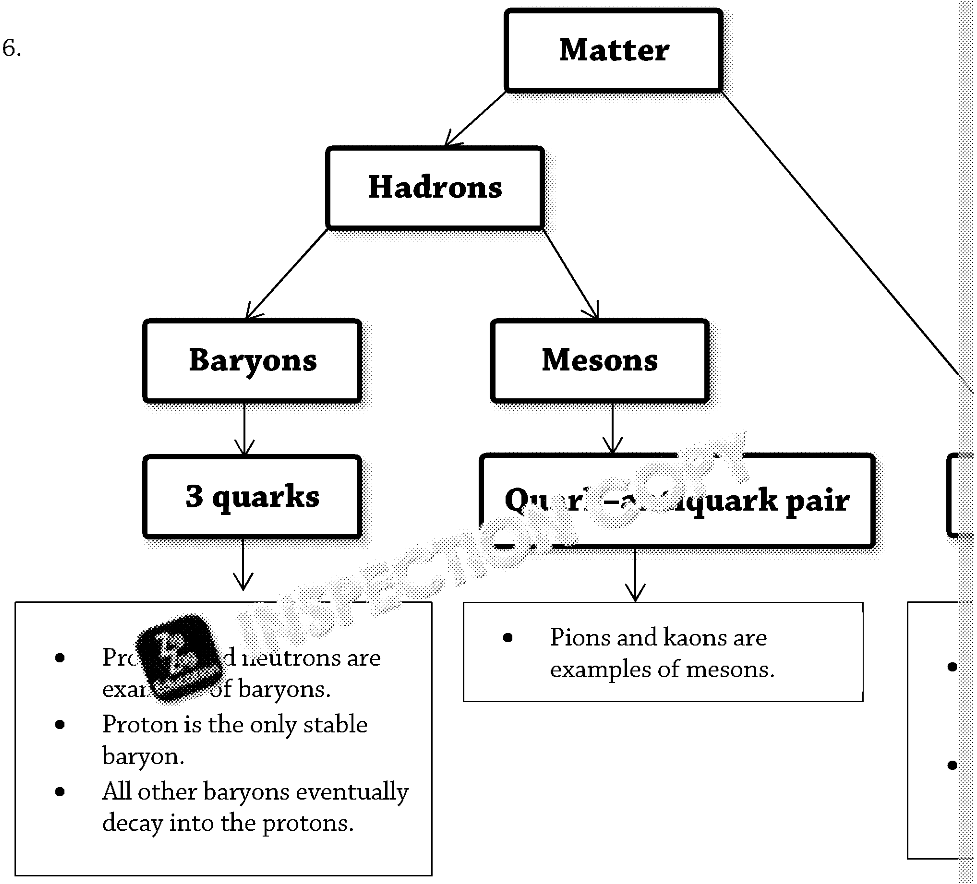
$E_o = 8.2\times10^{-14}$ J

$hf_{\min} = 8.2\times10^{-14}$ J

$f_{\min} = \frac{8.2\times10^{-14}}{6.63\times10^{-34}}$

$f_{\min} = 1.2\times10^{20}$ Hz

6.



7. A quark is an elementary particle that is the smallest known constituent that makes

8. a) uud
   b) $\bar{u}\bar{d}\bar{d}$
   c) $u\bar{s}$
   d) $d\bar{d}$ or $u\bar{u}$

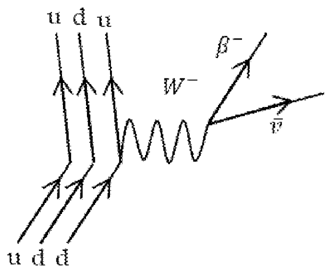
9. a) Up, down, strange
   b) $\frac{1}{3}$
   c) Charge of antiquarks: antiup, antidown, antistrange, is $-\frac{2}{3}, +\frac{1}{3}, +\frac{1}{3}$ respecti

10. a) Valid: Charge, strangeness, and baryon number are conserved.
    b) Invalid: Charge and lepton number are not conserved.
    c) Invalid: Baryon number is not conserved

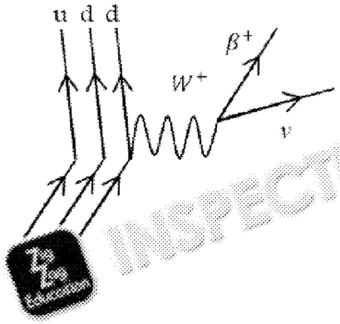
11. a) $\mu^- \rightarrow e^- + \bar{v}_e + v_\mu$
    b) $K^0 + p \rightarrow n + \pi^+$

12. a) Strong nuclear interaction
    b) Weak nuclear interaction
    c) In… ti… …ge particles are always created in pairs
    d)
    - …s
    - …dds

13. a)



b)



12: Radioactive decay

1. $^{42}_{19}K \rightarrow ^{42}_{20}C + ^{0}_{-1}e + \overline{v_e}$

   $^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ^{4}_{2}He$

2.

Type of radiation	Nature	Range in air	Ionisation	Absorp
Alpha	Two protons + two neutrons	<100 mm	Creates around 10^4 ions per cm in air	Stopped b metal foi pape
Beta	Electron or positron	<1 m	Creates around 100 ions per mm in air	Stopped 3–5 mm alumini
Gamma	Photon of energy	Obeys inverse square law	Weakly ionising	Stopped several c lead

3. Mass before = $m_U + m_n$ = (235.0439 + 1.0087) u = [illegible]26 u

   Mass after = $m_{Kr} + m_{Ba} + 3 \times m_n$ = [illegible] 142.9206 + 3 × 1.008[illegible]

   $\Delta m = m_{before} - m_{after}$ = [illegible] 235.8662) u = 0.1864 u

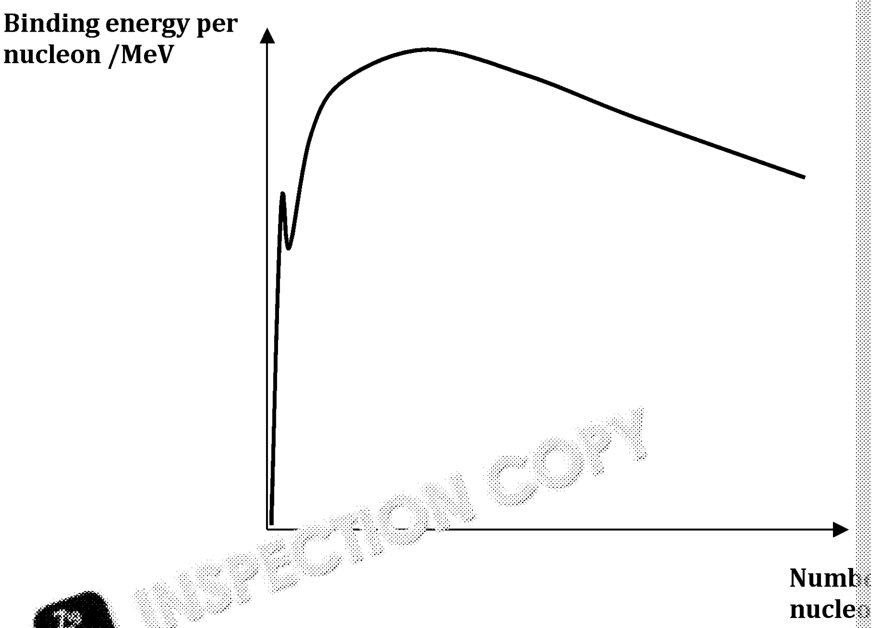
   ΔE = 0.1864 × 93[illegible] MeV

4. $\Delta m = Z$[illegible]$(A - Z)m_n - M_{nucleus}$

   Δm = 38 × 1.0073 u +(90 − 38) × 1.0087 u −89.9077 u = 0.8221 u

   ΔE = 765.8 MeV

5.



6. Nuclear fission is the process of a larger nucleus splitting into two smaller nuclei, w separate nuclei fusing together to produce a larger nucleus.

7. It cannot be determined when the next decay will occur, or which atoms will be the

8. a) $N = N_o e^{-\lambda t}$

$N = 4.7 \times 10^{24} \times e^{-2.5\times10^{-4}\times2400}$

$N = 2.6 \times 10^{24}$

b) $A = \lambda N$

$A = 2.5 \times 10^{-4} \times 2.6 \times 10^{24}$

$A = 6.5 \times 10^{20}$ Bq

c) $A = A_o e^{-\lambda t}$

$A_o = \frac{A}{e^{-\lambda t}}$

$A_o = \frac{6.5 \times 10^{20}}{e^{-2.5 \times 10^{-4} \times 2400}}$

$A_o = 1.2 \times 10^{21}$ Bq

9. a) 5 days

b) $T_{1/2} = \frac{\ln 2}{\lambda}$

$\lambda = $ [illegible]

$\lambda = \frac{\ln 2}{5 \times 24 \times 60 \times 60}$

$\lambda = 1.6 \times 10^{-6}\ \text{s}^{-1}$

10. • Fission can be induced by hitting the uranium isotope $^{235}_{92}U$ with neutrons.
• The uranium isotope is split roughly into two equal smaller nuclei and two or t released.
• Fission (thermal) neutrons can be harnessed and used to cause more fission ev induced.

11. The critical mass of a fissile material is the minimum mass required to sustain fissio during fission events going on to induce fission in other nuclei.

12. • The moderator keeps the neutrons at a low enough speed to be able to induce f
• The control rods absorb neutrons, stopping runaway fission events. They can b the situation.
• The coolant extracts the heat and allows it to be ... er..d to be used to prod

13: Medical imaging

1. X-rays ... uc..d by accelerating electrons through a potential and colliding ther electron... e target and suddenly decelerate, their kinetic energy is converted to

   Electrons are released via thermionic emission – the cathode heats up and releases e As the electrons are accelerated, they gain energy, $E = eV$.

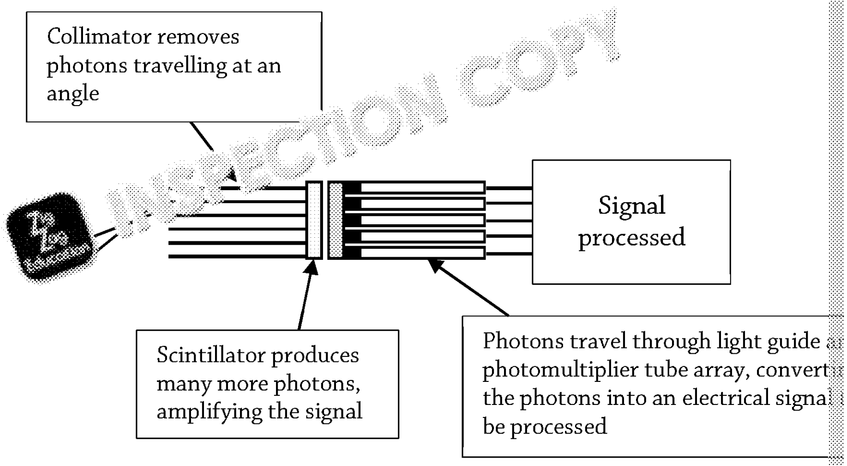
2. $I = I_0 e^{-\mu x}$
   $\mu = -\frac{1}{x}\ln\frac{I}{I_0} = -\frac{1}{3.50} \times \ln 0.122 = 0.6011\ \text{cm}^{-1}$
   $\mu_m = \frac{\mu}{\rho} = \frac{0.6011}{1.8} = 0.334\ \text{cm}^2\ \text{g}^{-1}$

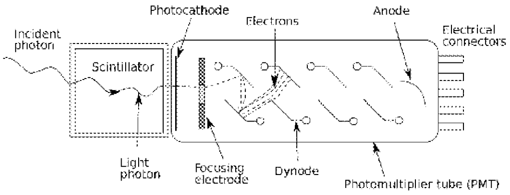
3. **Simple scatter:** 1–20 keV. X-rays are absorbed and re-emitted by atoms without ch
   Photoelectric effect: < 100 keV. X-rays are absorbed by an electron which then lea
   Compton effect: 0.5–5.0 MeV. X-rays are partly absorbed by an electron leaving th reduced energy.
   Pair production: >1.02 MeV. X-rays are converted into an electron–positron pair w

4. A CT scan involves a series of narrow beams of X-rays passed over the patient.
   Each beam produces a 360° image of a 'slice' of the patient, and the camera then mo the next 'slice'.
   CT scans are much slower and more expensive than traditional X-rays, but produces
   CT scans can also pose the risk of higher X-ray doses to the patient.

5. Gives off gamma rays so can be detected by a gamma camera. Half-life of around six molecules so can be made to go to a specific site.

6.



7. 

In a photomultipl
converted into a
then amplified in
electrons.

8. Ultrasound scans use sound energy to look inside the body non-invasively.
   - At each tissue boundary, some energy is reflected back.
   - The amount of energy reflected back depends on the specific acoustic impedan
   - The reflections can be used to build up an image.

9. Piezoelectric materials expand and contract wher ... AC ... rent is applied to them.
   - Current oscillations cause contrac...
   - Pressure differences caus... ... pid contractions create sound waves.
   - The sound wav... ... perform the ultrasound scan.
   - Pi...tr... ...als can also work in reverse, by converting sound energy to
   - T... ...nt is detected and used to build up a picture.

10. A-scans are single short pulses of sound.
B-scans are a rapid series of A-scans.

11. Advantages
   - Non-invasive
   - Useful for soft tissues
   - Inexpensive and portable

   Disadvantages
   - Can't see behind hard tissue
   - Needs a skilful technician

12. $Z = \rho c$
$\rho = \frac{Z}{c} = \frac{6.48 \times 10^6}{3500}$
$\rho = 1850$ kg m^{-3}

13. $Z_{fat} = 952 \times 1450 = 1.380 \times 10^6$ kg m^{-3}
$\frac{I_r}{I_i} = \left(\frac{Z_{fat} - Z_{skin}}{Z_{fat} + Z_{skin}}\right)^2 = \left(\frac{1.380 \times 10^6 - 1.99 \times 10^6}{1.380 \times 10^6 + 1.99 \times 10^6}\right)^2$
$\frac{I_r}{I_i} = 0.0328$

14. Ultrasound can be used to measure the blood flow velocity by using the Doppler eff
into the blood, and it is reflected back, with the change ir ... ency giving the velo

15. $\frac{\Delta f}{f} = \frac{2v\cos\theta}{c}$
$v = \frac{c\Delta f}{2f\cos\theta} = \frac{1570 \times 9.16 \times 10^{-4}}{2 \times 6.00 \ldots}$
$v = 0.20\ldots$ s^{-1}

16. In a PE... a positron-emitting tracer is injected into the patient.
The positron emitted quickly interacts with an electron, and the two annihilate.
Two gamma rays are emitted at 180° from one another. The two gamma rays are de
annihilation is calculated.

17. ^{18}F is used as it can form a molecule called fludeoxyglucose (FDG), which is treated i
body. This means that FDG quickly moves towards areas of the body with high rate
^{18}F also emits positrons; therefore, the gamma rays produced by them annihilating c
The two-hour half-life means little risk is posed to the patient.