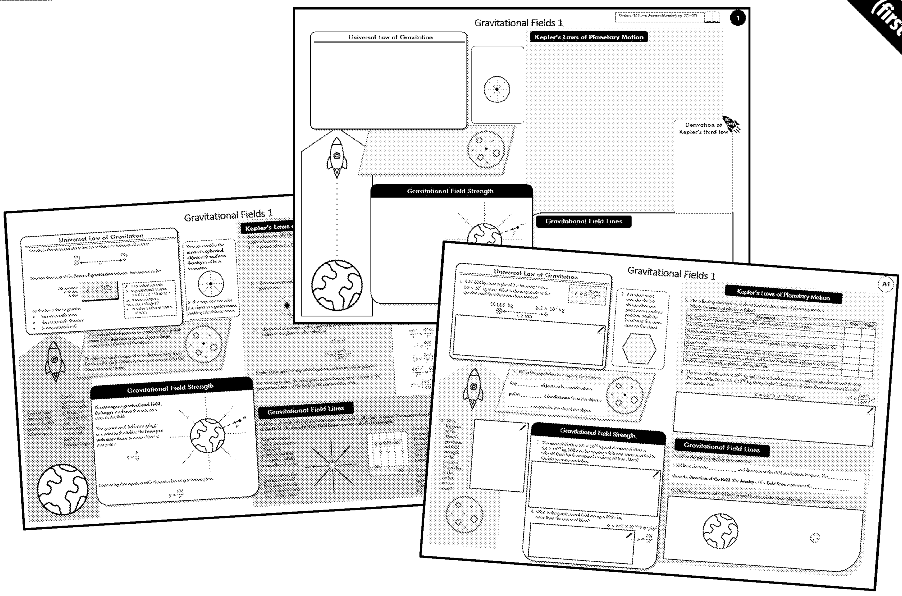
Physics International Baccalaureate Diploma Programme

2023 specification
(first exams in 2025)



Topic on a Page

for IB Physics

Theme D: Fields

zigzageducation.co.uk

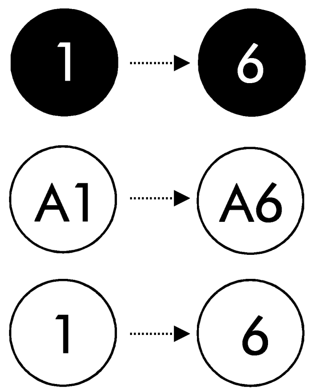
POD 12468

Contents

Teacher’s Introduction

This Topic-on-a-page resource has been designed to help your students revise the key points of each topic and test their knowledge after you have taught each section of the **IB Physics: Theme D – Fields** specification from topics 1 to 4. Each page is closely tied to the IB specification, ensuring all aspects of the course are covered. Two of the topics are covered by two pages each, while the other two topics are covered on a single A3 page each.

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 the IB Physics course.
2. **Activity pages**: these are identical to the Topic-on-a-page sheets, but contain a 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-only 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 fill 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 size, although they are still usable at A4 with no loss of detail. When photocopying activity pages on A3, we suggest photocopying the relevant worksheet on the reverse. If using at A4 size, we suggest photocopying each A3 activity ‘worksheet’ (for writing answers) as a double-sided A4 page to avoid shrinking the space available for answers.

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

- **Bullet-point processes** – complex processes and lists have been summarised into quick, easy-to-learn points.
- **Illustrative diagrams** – detailed diagrams that visually represent a concept or an event.
- **Method and calculation boxes** – concisely state the equations used in required calculations.
- **Tips and tricks** – extra useful information that can help students when solving problems.

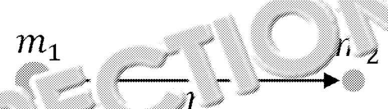
We hope you find these pages useful during your teaching and your students’ revision.

H Sproul, May 2024

Gravitational Field

Universal Law of Gravitation

Gravity is the universal attractive force that acts be... all ...att



...ton ... force of gravitation between two masses to be:

This equation is in the data booklet

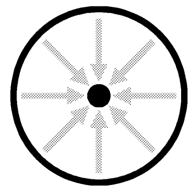
$$F = G\frac{m_1 m_2}{r^2}$$

F = force due to gravity
G = gravitational constant = 6.67×10^{-11} N m² 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
- is proportional to G

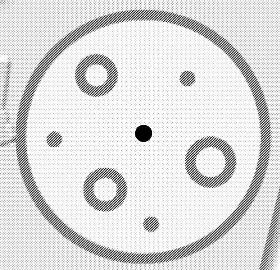
You can consider the **mass** of a **spherical object** with **uniform density** to all be at its **centre**.

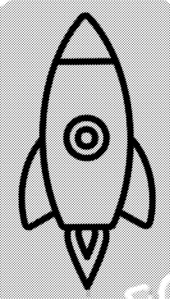


In this way, you consider the object as a **point mass**, making calculations easier.

Any **extended object** can be considered as a **point mass** if the **distance** from the object is **large** compared to the size of the object.

The Moon is small com... to i... dis...ce away from Earth. In the E...r...M... ...em, you can consider the Moo... ...





A rocket must overcome the force of Earth's gravity to lift off into space.

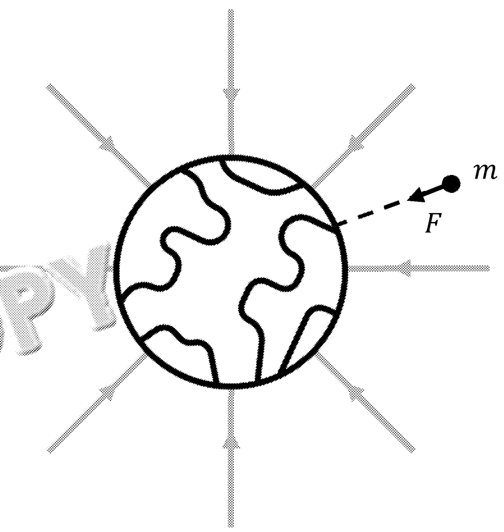
Earth's gravitational field strength, g, becomes weaker as the distance between the rocket and Earth, r, becomes larger.

Gravitational Field Strength

The **stronger** a **gravitational field**, the **larger** the **force** that acts on a mass in the field.

The gravitational field strength, g, at a point in the field is the **force per unit mass** that acts on an object at that point.

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



Combining this equation with Newton's law of gravitation gives:

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

Kepl

Kepler's

Kepler's
1. A p

2. The giv

3. The rad

Kepler's

For orbi gravitat

Field lin **of the f**

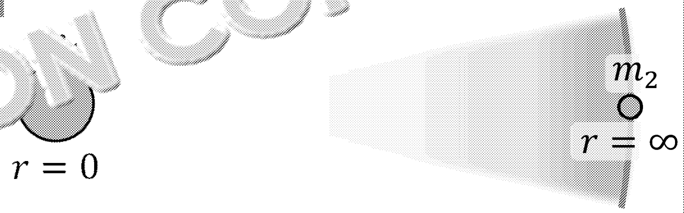
All grav forces a Therefo gravita lines p **towar**

From fa gravita lines ar point t from al

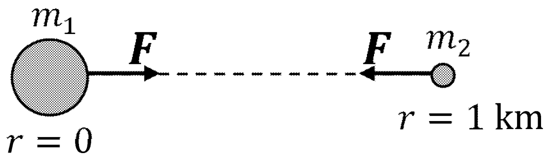
Gravitational Fields 2 – Additional Higher L

Gravitational Potential Energy

A mass, m_2, is an infinite distance away from another mass, m_1. A gravitational forc… between m_1 and m_2. There is n… …tial en…g… stored between m_1 an… m_2.



…ught closer to m_1, a gravitational force …tween m_1 and m_2. The work done to bring m_2 closer to m_1 is now stored as potential energy between m_1 and m_2.



If the masses are free to move, the attractive gravitational force will do work to bring m_1 and m_2 even closer, storing more potential energy. The potential energy stored between two masses is called **gravitational potential energy**, E_p.

$$E_p = -\frac{Gm_1m_2}{r}$$

The gravitational potential energy stored between two masses is:

- **larger** and more negative if eith… …a… **is larger**
- **la**… and …ore negative if the …sses are **closer**
- **zero** if one mass is **at infinity**

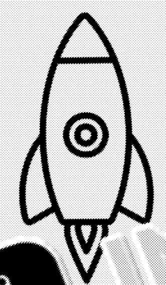
Gravi…

The **work**… gravitation… from this …

The gravit…

The gravit… point in a…

Escap… a G… …tational Field



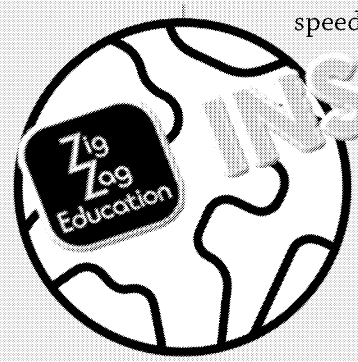
…ch …a rocket, in the gravitational field of another …uch as Earth, will have gravitational potential energy.

If the rocket wants to move away from Earth, the rocket will need to do work to decrease the magnitude of its gravitational potential energy, thereby increasing its distance from Earth.

The work the rocket does during lift-off is first converted to kinetic energy, moving its position away from Earth. The faster the rocket travels, the more kinetic energy the rocket has to convert to gravitational potential energy, so the further away from Earth the rocket can travel.

A rocket can completely escape the gra…tati…al fie… …f Earth if it has enough kinetic … …spe…ated to this amount of kin… …y i… …ed the escape speed, $v_{es…}$

$$v_{esc} = \sqrt{\frac{2GM}{r}}$$



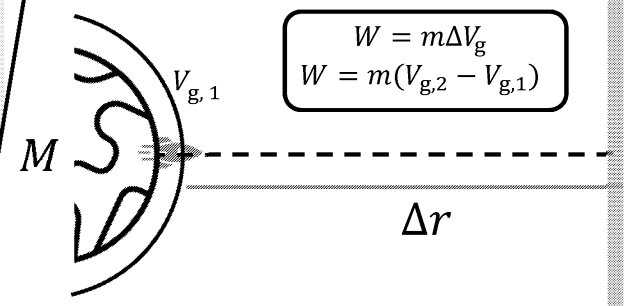
This equation depends on the distance between the two masses. Therefore, it can be used to find the escape velocity from any point in a gravitational field.

Doing…

To move a mass to a n… gravitational field, yo… on the mass. A rocket… accelerate itself off Ea…

The work done, W, moving a mass m to a new g… potential is calculated using:

$$W = m\Delta V_g$$
$$W = m(V_{g,2} - V_{g,1})$$



Sa…ellites in Orbit

A stationary object will fall towards a larger object, su… along an equipotential line, perpendicular to the gravi… Earth. This curved path around a large object is called…

Derivation of the Orbital Speed Equation

For a satellite to stay in orbit, the centripetal force causin… circular path must equal the gravitational force between t… satellite and the larger object.

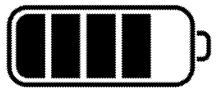
$$F_c = F_g$$
$$\frac{mv_{orbtial}^2}{r} = \frac{GMm}{r^2}$$

The orbital velocity of the satellite must therefore be:

$$v_{orbtial} = \sqrt{\frac{GM}{r}}$$

What is Electric Charge?

Electric charge, q, is a property of an object that allows the object to interact with electric fields.



The more electric charge an object has, the more ... with ... fields ... ch...

Like ... electric charge depends only on the object and not on the situation the object is in.

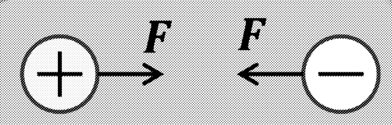
Coulomb's Law

Coulomb's law states that the force between two point charges depends on their charges, q_1 and q_2, and their separation ... constant ...:

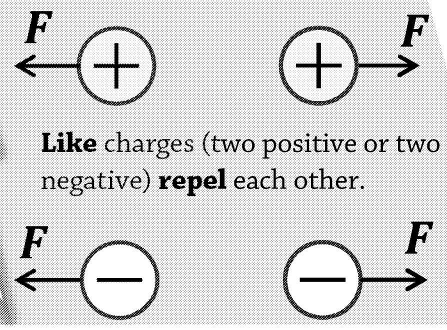
$$F = k\frac{q_1 q_2}{r^2}$$

$$k = \frac{1}{4\pi\varepsilon_0}$$

There are two types of electric charge: positive and negative.



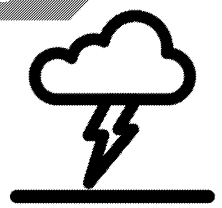
Opposite charges (one positive and one negative) **attract** each other.



Like charges (two positive or two negative) **repel** each other.

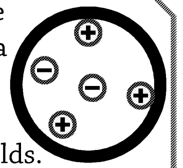
Transferring Electric Charge

Objects can gain or lose electric charge via three ways: friction, electrostatic induction, and conduction.



Conservation of Electric Charge

The law of conservation of electric charge states that the **total electric charge** in a closed system will stay **constant**. The charge of an object will only change if it interacts with other objects or electric fields.

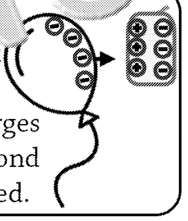


Friction

Rubbing two objects together can cause electric charge to be picked off one object and transferred to the other. Insulators will stay charged ... friction.

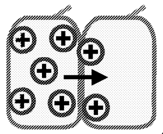
Electrostatic Induction

A charged object ... will attract and repel charges in the second object. If the charges are free to move, the second object will become charged.



Conduction

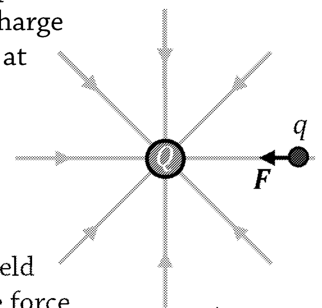
Electric charges can pass from one charged object to another when the objects are in contact. Charges will transfer until the electric charge of each object is equal in both sign and magnitude.



Electric Field Strength

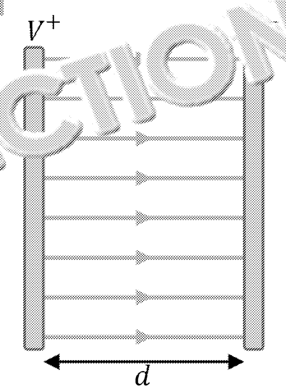
Electric field strength, E, at a point is equal to the force per unit charge that acts on an electric charge at that point in the field.

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



This is like the gravitational field strength, which is equal to the force per unit mass.

Electric fields can take any shape depending on the arrangement of electric charges. Two ... plates with opposite charges will create a uniform field. The field lines all point in the same direction.



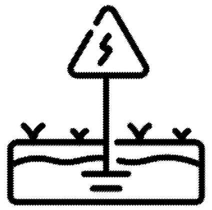
The density of electric field lines between parallel plates is constant. Therefore, the electric field strength between parallel plates is constant.

You can calculate this electric field strength from the gap between the plates, d, and the potential difference between the plates, V.

$$E = \frac{V}{d}$$

Grounding

A build-up of electric charge in an object can be dangerous. Large transfers of charge transfer a lot of energy which can burn people or start fires. Objects are grounded by connecting the object to the ground with a conducting wire. Any excess charge will flow to the ground, so no charge builds up in the object.



In 1910, R...
charge is q...

Millikan sp...
oil. Millika...
knocked el...
these nega...
droplets p...

At the top ...
Millikan el...
electric fie...
would feel...

Millikan ad...
acting upw...
down on th...

Millikan ob...
happened,...
plates to c...

Millikan fo...
potential d...
increased i...
quantised ...

We now kn...

Just like gr...
in space. Th...

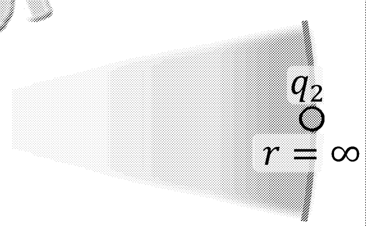
Electric field...
Field lines a...
forming loo...

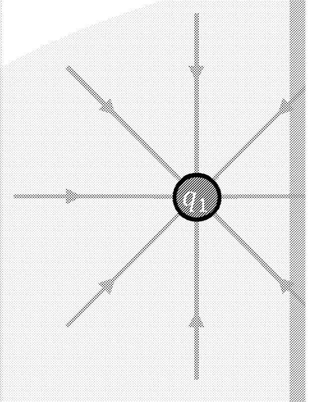
Near an elec...
electric fie...

Electric and Magnetic Fields 2 – Additional Higher L

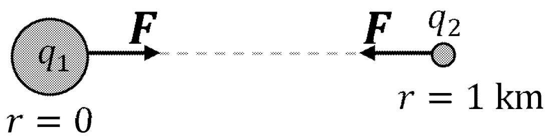
Electric Potential Energy

A test charge, q_2, is an infinite distance away fr... another charge, q_1. An electric force wil... between these charges, so there i... potential energy stored between t... e ...g...





...ght closer to q_1, a repulsive electric ... between both charges. The work done to ...g q_2 closer to q_1 is now stored as electric potential energy between q_2 and q_1.



The **electric potential energy**, E_p, stored between two charges is calculated using:

$$E_p = k\frac{q_1 q_2}{r}$$

Doing Work to Move an Electric Charge

Moving an electric charge in an electric field will result in a **change in el...tr... po...ial e...rgy** (unless the electric potential does not change). This change in energy comes from th... elec...ic cha... ...oing work**, W, to move to a new electric potential.

$$W = \Delta E_p$$

The work done to move a charge ... ...o th... ...oduct of the charge and the change in the electric potential.

$$W = q\Delta V_e$$

...nits for Work Done

Wo... ...transfer of energy. Therefore, work is measured in units of energy such as **joules**, J. Sometimes, problems involve tiny electric charges, like electrons. The energies involved are also tiny, so you may find it more convenient to use **electronvolts**, eV, instead of joules.

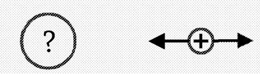
Remember, one electronvolt is the energy it takes to move an electron across an electric potential of one volt.

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

What is a Test Charge?

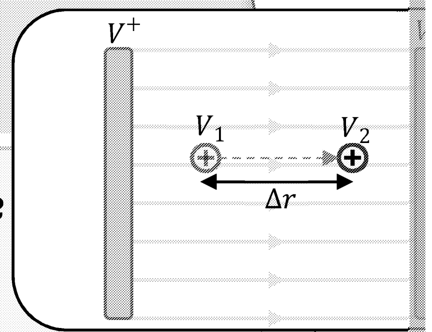
How would you measure the strength of an electric field at a point near an unknown charge in the real world?

The easiest solution is to place a second charge at that point and see how this second charge behaves.



The more the s...d charge accelerates, the st...e ...d at that point. ...i... seco... ...harge is a test charge.

How are ele... uniform ele...



The ...

Subs...

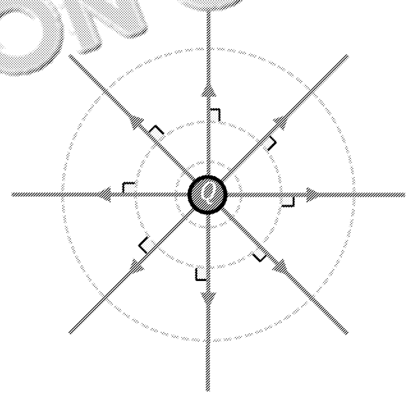
Eq...

Equipotential Lines

Just like gravitational fie...s, ...ines with constant el...ric p... ...ipotential lines.

Ever... ...ial line:

- h... ...e electric potential at any point along the line
- is always perpendicular to the electric field lines
- always forms a closed loop



Moving an electric charge along an equipotential line takes no work because the electric potential does not change.

$$W = q\Delta V$$
$$W = q(0)$$
$$W = 0 \text{ J}$$

Equ...

The real w... dimension... dimension... equal pote... do not for... surface tha... These surf... **equipoter...**

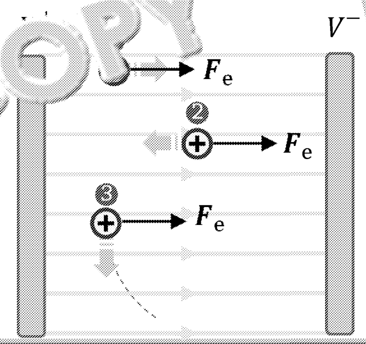
Motion in Electromagne

Charged Particle Moving Through an Electric Field

Any charged particle in an electric field will experience an **electric force** including those in motion.

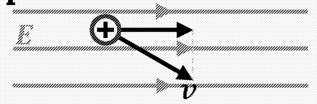
The direction of this electric force relative to the d... motion of a charge will make the charg... **d** ... (...), **slow down** (2) or stay at a **con**... **peed** (...).

The electric f... ma... the direction of motion of the ... ge take a **curved path** (3).



Accele... arge

An electri... will accelerate or decelerate a charge if a **component** of the charge's **velocity** is **parallel** to the **field**.

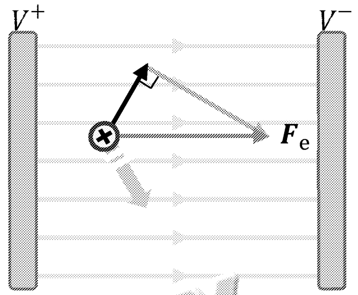


The **electric force will do work** on the charge, changing the charge's kinetic energy and speed.

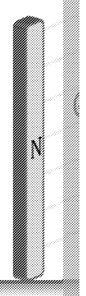
What Causes Circular Motion of Charged

In both electric and magnetic fields, if a charge moves **at an angle to the field**, the charge will follow a **curved path**. Why does the charge take this curved path?

For a charge moving through an electric field, the force acts in the direction of the field. If the charge is moving at an angle to the field, there will be a **force component** that acts **perpendicular to the motion of the charge**.



For a charge moving at an angle through a magnetic field, the force acts **perpendicular** to both the field and the **motion of the charge**.



Conservation of Energy

In any interaction, energy must be conserved.

When an electric field does work on an electric charge, electric potential energy is tr... to kinetic energy.

... ΔE_p

A magne... no ... on an electric charge so ... transferred to the charge.

You can ap... conservation of energy to problems to gain new information.

The M

The **magnitu**... m... force that acts on a moving charge depends on four fac... ma... of the **charge**, q, the **speed** of the charge, v, the **magnetic field str**... and the **angle** between the velocity of the charge and the magnetic field, θ.

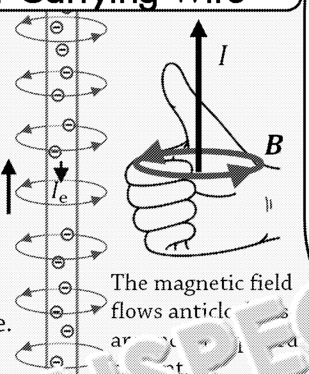
$$F_b = qvBsin\theta$$

The more perpendicular the charge moves relative to the magnetic field, the stronger the magnetic force because θ is closer to 90°.

Magnetic Field around a Current-Carrying Wire

An electric current in motion also has its own magnetic field. This means a current-carrying wire has a magnetic field.

You can find the direction using the right-hand thumb rule.



Magnetic Force on a Current-Carrying Wire

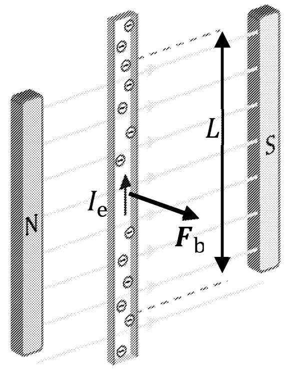
A wire carrying an electric current, I, is a thin piece of conducting material with many charges moving along its length, L. If a current-carrying wire is in a magnetic field, B, a magnetic force will act on each charge. The sum of all these forces results in a net magnetic force acting on the wire.

$$F_b = \sum qv...$$

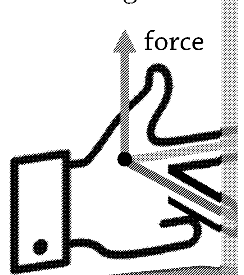
$$... n\theta \sum ... \left(\frac{...}{\Delta t}\right)$$

$$... = B\left(\sum \frac{q}{\Delta t}\right)(\Delta x)sin\theta$$

$$F_b = BILsin\theta$$



Just like for indi... charges, you can... left-hand rule to... determine the di... the magnetic for...



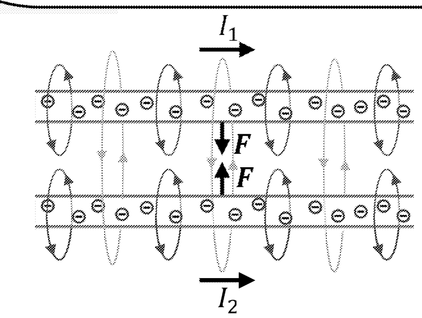
Tip

The second finger p... direction of conventi... I. This is the opposit... to the electron curre...

The mag... aro... current-carrying wires will inte... es w... exert a force on each other.

The force ...ngth, $\frac{F}{L}$, between two parallel wires separated by r can be calculated using:

$$\frac{F}{L} = \mu_0 \frac{I_1 I_2}{2\pi r}$$



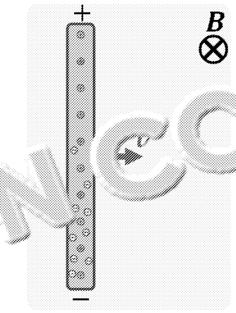
If two parallel wires carry a current in the same direction, the overall magnetic field makes the wires attract each other.

If two parallel wires carry a current in opposite di... the wires will repel each other.

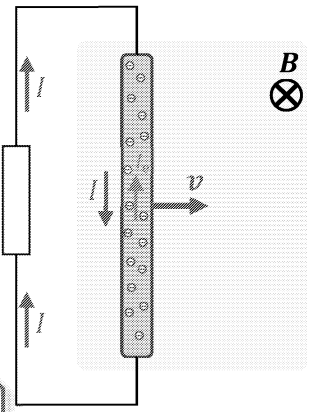
Induction – Additional Higher

Moving a Conductor in a Magnetic Field

If you move a conductor through a magnetic field, the field will induce an electromotive force (emf) on the electric charges in the conductor. The charges will start to move, creating an imbalance of charge. One end of the conductor will become positively charged while the other end will become negatively charged.



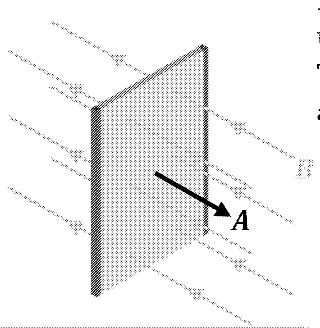
If you connect the conductor to a closed circuit, an electric current will flow through the conductor and the circuit.



For a straight conductor of length, L, moving perpendicularly through a uniform magnetic field at a constant velocity, the emf, ε, induced in the conductor is calculated using:

$$\varepsilon = BvL$$

Magnetic Flux

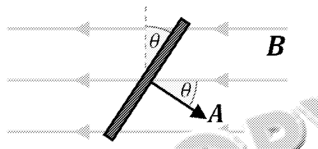


A magnetic field forms closed loops in all space around a magnet or an electric current. A magnetic field will pass through surfaces or objects, like the conductor above.

The measure of a magnetic field, $\boldsymbol{B}$, that passes through a specific area, A, is called the magnetic flux, Φ.

$$\Phi = BA\cos\theta$$

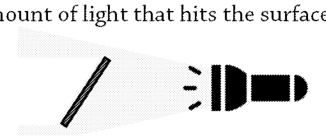
The magnetic flux through an area depends on the **angle** of the **area vector** relative to the magnetic field.



The more parallel the area vector is to the field, the more magnetic field lines that pass through the area, so the larger the magnetic flux.

Analogy

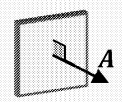
The more perpendicular a surface becomes to a light beam, the higher the amount of light that hits the surface.



What is an Area Vector?

Every area has a vector that shows how the area interacts with other vector quantities.

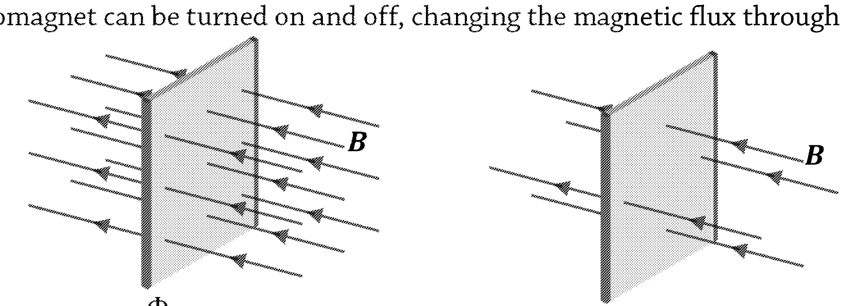
The direction of the area vector points perpendicular away from the surface area.



The magnitude of the area vector is equal to the size of the area.

[illegible] Changing Magnetic Flux

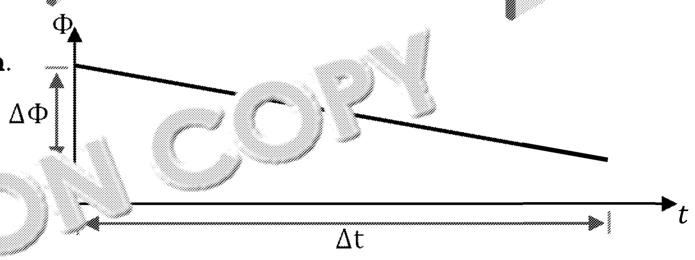
The magnitude of the magnetic flux passing through an area can change with time. For example, a permanent magnet can move past a conducting sheet, or an electromagnet can be turned on and off, changing the magnetic flux through a conductor.



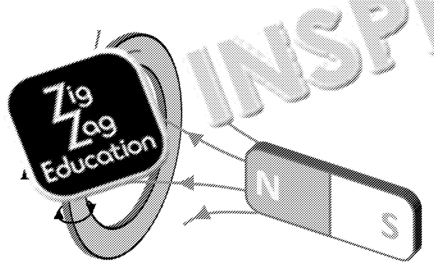
The rate of change of magnetic flux through a conductor is proportional to the emf induced in the conductor.

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$$

This relationship is called **Faraday's law of induction**.

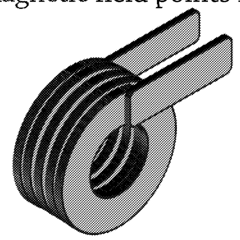


Do you notice the negative sign in Faraday's law? This shows that the current from an induced emf always has a magnetic field that **opposes** the inducing magnetic field. This is called **Lenz's law** and comes from the law of conservation of energy.



The magnet moving towards the conducting coil on the left induces an electric current in the coil. Due to Lenz's law, this induced electric current must flow anticlockwise, so the current's own magnetic field points in the opposite direction to the magnet's field.

If you connect multiple conducting loops into a coil, each loop will experience a change in magnetic flux, further increasing the emf. Hence, N, the number of loops, is added to Faraday's law of induction.



An emf is… this can… 1. The… 2. The… Electric g… move ma… induces a…

This simp… south pol…

When the… moving u… moving d… left-hand… current m… anticlockw…

When the… bottom ed… parallel to… zero, there… so no emf… at this poi…

As the coi… again ind… use a slip… and negat… This make… smooth a…

The coil r… is vertical… induced i…

The coil c… sinusoida…

A coil is made up… When a current f… generates a magn… loop induces an e… Lenz's law, this e… The magnetic fie… emf in loop 2 tha… current, and vice… inductance mean… **electric curren…**

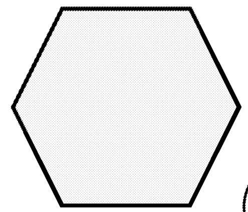
Gravitational Fields 1

Universal Law of Gravitation

1. A 36 000 kg mass is placed 1.2 km away from a 8.2×10^7 kg mass. What is the magnitude of the gravitational force between these masses?

$F = G\frac{m_1 m_2}{r^2}$

2. A student must consider the 2D object below as a point mass to solve a problem. Mark the location of this point mass on the object.

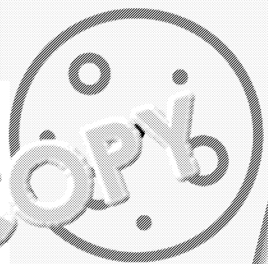


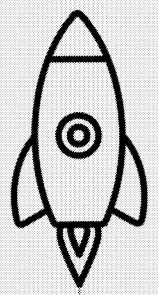
3. Fill in the gaps below to complete the sentence.

Any __________ **object** can be considered as a

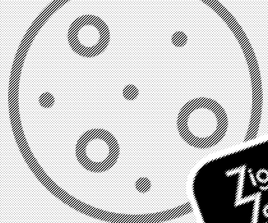
point __________ if the **distance** from the obje...

__________ compared to the size...





4. What happens to the Moon's gravitational field strength at the position of a rocket as the rocket moves away?



Gravitational Field Strength

5. The mass of Earth is 6.0×10^{24} kg and the mass of Mars is 6.4×10^{23} kg. Will a rocket require a different amount of fuel to take off from Earth compared to taking off from Mars? Explain your answer below.

6. What is the gravitational field strength 8000 km away from the centre of Mars?

$G = 6.67 \times 10^{-11} \text{Nm}^2/\text{kg}^2$

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

7. The following st...
Which are **true**...

The Sun orbits a pl...
An elliptical orbit h...
Planets travel faste...
The area covered b... planet's orbit.
If a planet's period...
The electromagnet...
Kepler's laws only a...

8. The mass of Ear... The mass of the... around the Sun...

Gravita...

9. Fill in the gap to...

Field lines show th...

show the **directio**...

10. Draw the gravit...

Gravitational Fields 2 – Additional Hig

Gravitational Potential Energy

1. A 2.0 kg mass is moved from infinity to 7.5 m away from a 6.3 kg m s. What is the gravitational potential energy stored between asses?

$G = 6.67 \times 10^{-11} \text{Nm}^2/\text{kg}^2$

$E_p = -\frac{Gm_1 m_2}{r}$

2. Fill in the blanks to complete the sentences.

The gravitational potential energy stored between two masses is ______________ negative unless one mass is at infinity. The ______________ two masses are, or the ______________ their mass, the higher the gravitational potential energy stored between the masses.

Gravitatio

5. What is the g Write your de

6. A 1 kg mass What is the mass? What

Escaping a Gravitat F

3. A private roc to launch a satellite into an orl 4 fr Earth's centre. How fast should the to place this satellite into its orbit?

$v_{esc} = \sqrt{\frac{2GM}{r}}$

$v_{orb} = \sqrt{\frac{GM}{r}}$

4. A satellite is currently orbiting the Moon 650 km above the Moon's surface. The satellite wants to move to a new orbit, 5400 km above the Moon's surface. By how much should the satellite decrease its speed? The M s a radius of 1737 km and a mass of 7

Doing Work

$W = m\Delta V_g$

7. How much work should a 430 kg rocket do to mov a gravitational potential of 65 J/kg to 78 J/kg?

Satellites in Orbit

H st must a planet travel to orbit the Sun $\times 10^{18}$ m? The mass of the Sun is 2.0×10^{30} kg.

Electric and Magnetic Fie

Coulomb's Law

1. Two charges, both 1.9 C, are separated by 4.3 m. What is the force that acts between the charges? In what direction will these charges move?

2. A physicist has two equal charg... $q_1 = q_2$, separated by ... The physicist d... the ...ge o... q_2 ar... m...ves ... tw... ar away ... w does the force ...et... the two charges change?

$$F = k\frac{q_1 q_2}{r^2}$$

$$k = \frac{1}{4\pi\varepsilon_0}$$

$$\varepsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N m}^2$$

a) the force doubles ☐
b) the force quadruples ☐
c) the force is halved ☐
d) the force does not change ☐

Transferring Electric Charge

3. Match the description to the type of electric charge transfer.

- Electric charges can pass from one charged object to another when the objects are in contact.
- A charged object near a second object will attract and repel charges in the second object. If the charges are free to move, the second object will become charged.
- Rubbing two object... ca... cause electric cha... ...ed off one object and ... to the other.

- Conduction
- ...tic...
- Induction

Conservation of Electric Charge

4. In the box below, write down the law of conservation of charge.

Electric Field Strength

5. An electric field exerts a 1.5 mN force on an electron. What is the electric field strength at the position of the electron? The charge of an electron is 1.602×10^{-19} C.

Grounding

6. Fill in the blanks to compete the sentences. Objects are grounded by connecting the object

to the ground with a ____________ wire.

Any excess ___________ wi... ...v... the

ground, so ... ch...ge b... ...p in the object.

7. An electric field between two paral... ... a strength of 84 V/m ... tes ... What is the pote...nce ...een the plates?

... +3 ... charge is accelerated by an electric field across a ... m distance. The force the electric field exerts on the charge is 75 mN. What is the potential difference between the start and end position of the charge?

9. In the box bel... his observatio...

10. On the axes ...

Charge

Ele...

11. Draw the elec... these three ch...

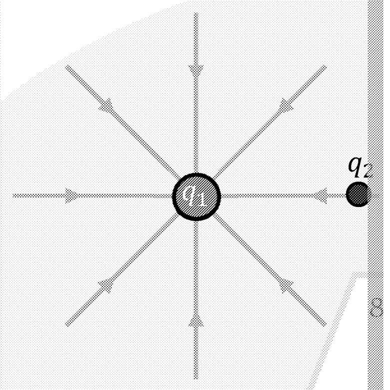
Electric and Magnetic Fields 2 – Additional

Electric Potential Energy

$k = 8.99 \times 10^9$ N m²/C² $E_p = k\frac{q_1 q_2}{r}$

1. How much electric potential energy is stored between two -7.4 C charges placed 62 cm apart?

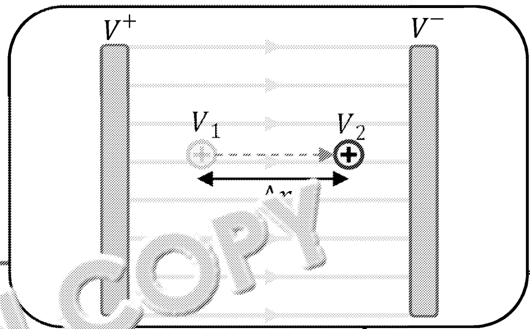
2. A +1.6 mC charge and a … C charge are held at … storing 25 J of electric potential energy. What is the separation distance between the charges?



Doing Work to Move an Electric Charge

3. What is the change in electric potential energy of an electron when it is moved from an electric potential of 15 V to an electric potential of 8 V? The charge of an electron is -1.602×10^{-19} C.
   a) 15 eV ☐
   b) 7 eV ☐
   c) 1.9 eV ☐
   d) 0.5 eV ☐

4. An electric field does 25 … of work on a proton. What is the change in electric potential between the start and end points of the proton? A proton has a charge of 1.602×10^{-19} C.



… Work Done

5. Write a definition of the electronvolt relating it to joules. Then convert 2… × 10⁻¹⁷ J into electronvolts.

9. Fill in the blan…
The work done…

10. A student…
finds that…
by 3.6 V…

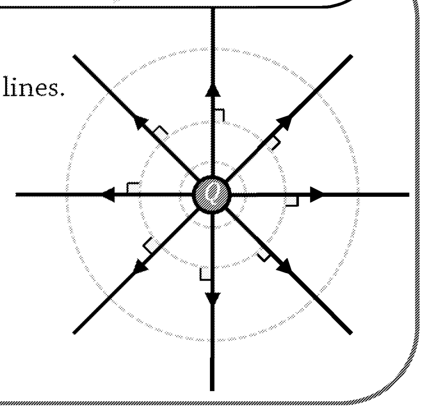
Equipotential Lines

6. Fill in the blanks to complete the sentences.

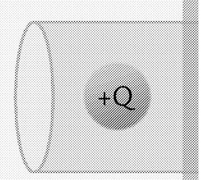
Electric fields have lines with constant electric ____________ called equipotential lines.

Every equipotential line:

- has the ____________ electric potential at any point along the line
- is always ____________ to the electric field lines
- always forms a ____________ loop



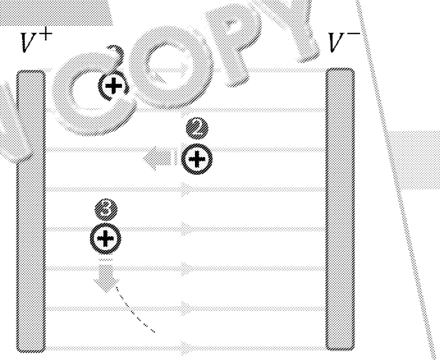
Equipote…

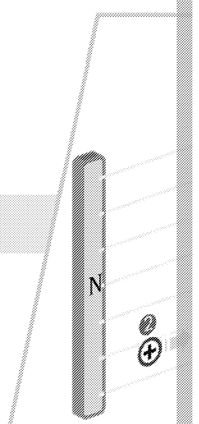


Charged Particle Moving Through an Electric Field

1. The diagram on the right shows three charges moving through a uniform electric field. Which charges experience an electric force?

   a) only charge 1 ☐
   b) charges 1 and 2 ☐
   c) charge 1, 2 and 3 ☐
   d) cha… 3 ☐





Accelerating

3. Explain why a stationa… electric charge will accelerate if placed in an electric field.

What Causes Circular Motion of Charged Part

4. Fill in the blanks to complete the sentences.

For a charge moving through an ________________ field, the force acts in the direction of the field. I…

________________ **to the motion of the charge**. For a charge moving at an angle through a magne…

charge. In both cases, a force acts ________________ to the velocity of the charge. This force acts as…

constantly turns the charge, making the charge take … curved, circular path.

Conservation of Energy

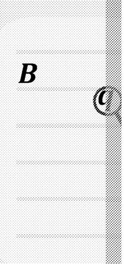
5. Which of the following statements is true?

   a) The energy of a closed isolated system must always stay constant. ☐
   b) The energy of … late system is alwa…
   c) The energy of a c… isolated system depends on the charge of the system. ☐

The Magne

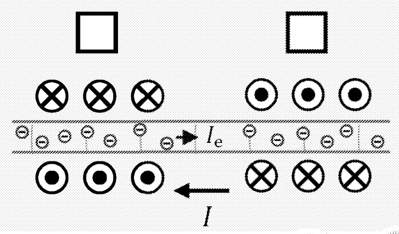
6. An electron is moving throu… a magnet… at 3.5 km/s and at a 60° angle to the field. The ma… s… …h is 50 mT. What magnetic force acts on the elect…

$F_b = q$…



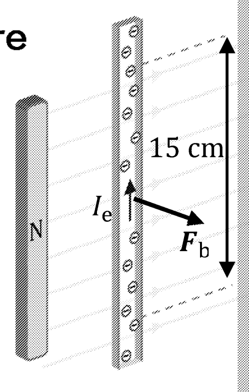
Magnetic Field around a Current-Carrying Wire

8. Which set of field symbols shows the correct direction of the magnetic field around this current?



Magnetic Force on a Current-Carrying Wire

9. A wire carrying a current of 25 mA is placed perpendicular to a uniform magnetic field. The field has a strength of 7.5 mT and 15 cm of the wire sits in the field. What is the size of the magnetic force that acts on the wire?



$F_b = BIL\sin\theta$

11. Two wires each … curr… 1.0 A in the sam… …re placed parallel to each o… …m apart. What is the force per unit length that acts on these wires?

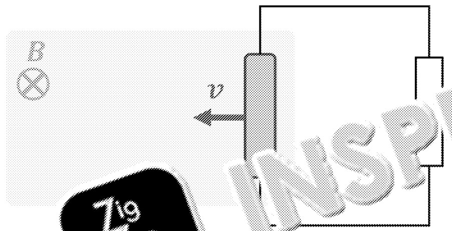
$\frac{F}{L} = \mu_0 \frac{I_1 I_2}{2\pi r}$

$\mu_0 = 4\pi \times 10^{-7}$ N…

Induction – Additional Higher Le

Moving a Conductor in a Magnetic Field

1. Which direction will a current flow around this circuit if the wire is moved to the left through the magnetic field?
   Draw arrows on the circuit to indicate the current's direction.

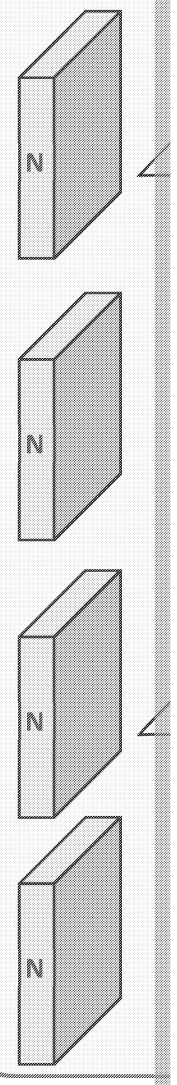


2. A conductor is moved perp... ular through a uniform magnetic field at ... The length of the conductor ... ar... field has a strength of 2... T. W... at ... induced in the conductor?

7. Describe tw

How c

8. Draw the cu rotating in a electric curr



Magnet Fl

$\Phi = BA\cos\theta$ $\varepsilon = BvL$

3. A sheet of copper with an area of $25\ \text{cm}^2$ is placed in a magnetic field at a 45° angle to the field. The magnetic field strength is 350 mT. What is the magnetic flux through the copper sheet?

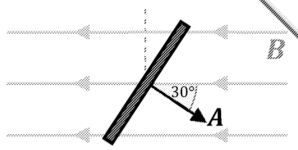
   a) $6.2 \times 10^{-4}\ \text{Tm}^2$ ☐

   b) $6.2\ \text{Tm}^2$ ☐

   c) $5.1 \times 10^{-3}\ \text{Tm}^2$ ☐

   d) $51\ \text{Tm}^2$ ☐

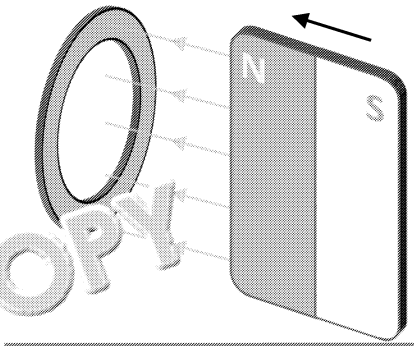
4. A magnetic flux of $6.4 \times 10^{-2}\ \text{Tm}^2$ passes through a conducting sheet with an area of $0.75\ \text{m}^2$. The area vector of the sheet makes a 30° angle with the magnetic field. What is the magnetic field strength?



A Ti... ...ing Magnetic Flux

$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$ $\varepsilon = IR$

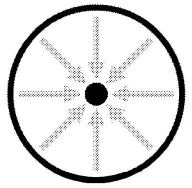
5. The north p... magn... towards a copper ring, inducing a current in the ring. The ring has an area of $3.0\ \text{cm}^2$ an... sun... the ring is perpendicular to the field lines from the magnet. The magnet moves towards the ... ery far away, where B at the ring is zero, to a position where B at the ring is 60 mT in 45 s. The ring has a ...stance, R, of 30 Ω. What is the current induced in the ring by the motion of the magnet?

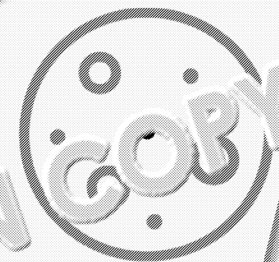


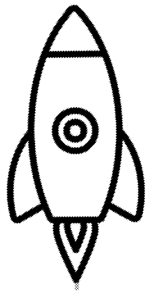
6. Fill in the gaps to complete the sentences.
   A coil is made up of multiple loops of a conductor. Wh
   from each loop induces an emf in the loops next to it.
   The magnetic field from loop 1 induces an emf in loop
   This self-inductance means **coils resist changes in** _

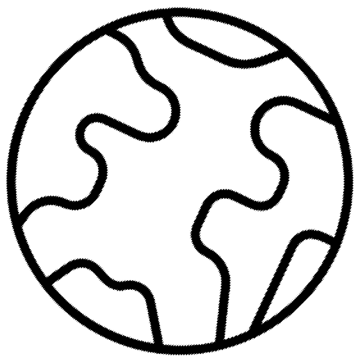
Gravitational Fields 1

Universal Law of Gravitation

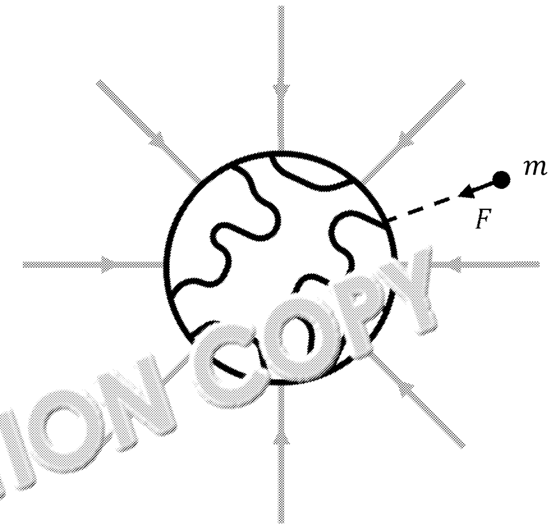








Gravitational Field Strength



Kepler's Laws

Gravitatio

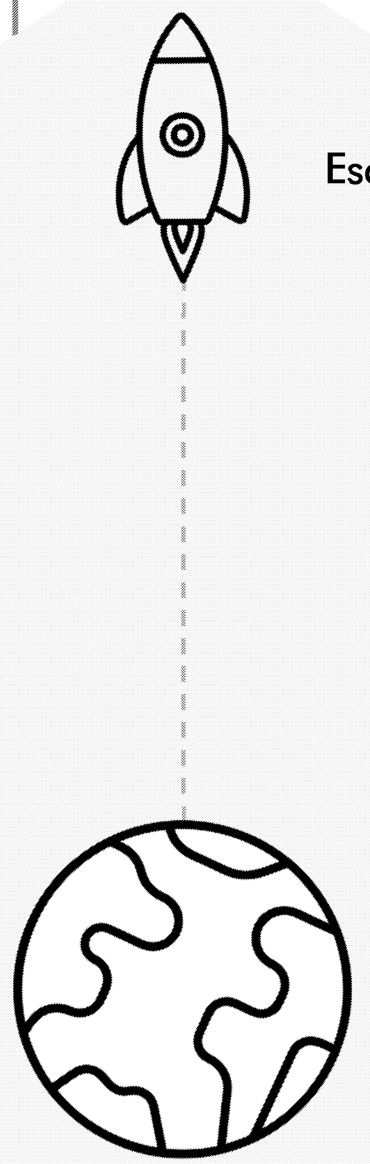
Gravitational Fields 2 – Additional Higher Level C

Gravitational Potential Energy

The gravitational potential energy stored between two masses is:

Gravitational P

Doing Work



Escaping a Gravitational Fiel

Satellites in Orbi

Derivation of the Orbital Speed Equation

What is Electric Charge?

Coulomb's Law

Transferring Electric Charge

Conservation of Electric Charge

Friction

Electrostatic Induction

Conduction

Electric Field Strength

Grounding

Electric and Magnetic Fields 2 – Additional Higher Level Co

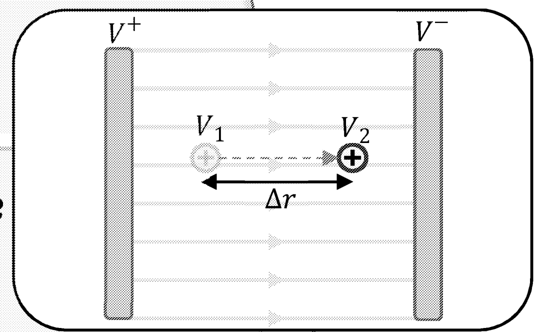
Electric Potential Energy

Doing Work to Move an Electric Charge

Units for Work Do

What is a Test Charge?

Electric



Equipotential Lines

Equipotential S

Motion in Electromagnetic Fiel

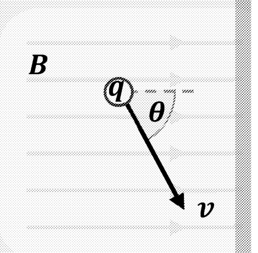
Charged Particle Moving Through an Electric Field

Accelerating Charge

What Causes Circular Motion of Charged Particles i

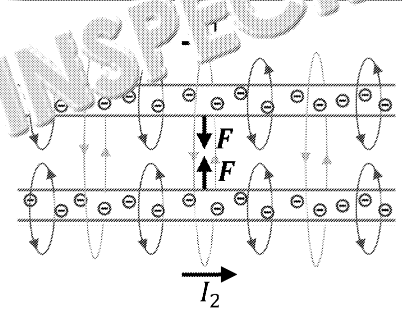
Conservation of Energy

The Magnetic Fo



Magnetic Force on a Current-Carrying Wire

Magnetic Field around a Current-Carrying Wire



Induction – Additional Higher Level (

Moving a Conductor in a Magnetic Field

Magnet Flux

What is an Area Vector?

Analogy

A Time-Changing Magnetic Flux

Self-Inductio

IB Topic on a Page, Theme D: Mark

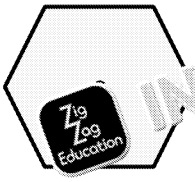
Gravitational Fields 1

1. $F = G\frac{m_1 m_2}{r^2}$

$$F = (6.67 \times 10^{-11}\text{Nm}^2/\text{kg}^2)\frac{(3.6 \times 10^4\ \text{kg})(8.2 \times 10^7\ \text{kg})}{(1.2 \times 10^3)^2}$$

$F = 1.4 \times 10^{-4}$ N

2.



3. Any ***extended*** **object** can be considered as a **point** ***mass*** if the **distanc**
compared to the size of the object.
4. At the position of the moving rocket, the Moon's gravitational field st
5. Yes, a rocket taking off from Earth will need more fuel because Earth'
than that of Mars. The rocket must overcome a larger gravitational fo
6. $g = \frac{GM}{r^2}$

$$g = (6.67 \times 10^{-11}\text{Nm}^2/\text{kg}^2)\frac{(6.4 \times 10^{23}\ \text{kg})}{(8.0 \times 10^6\ \text{m})^2}$$

$g = 0.67$ m/s²

7.

Staten
The Sun orbits a planet in an elli ca o it, with the planet at one
An elliptical orbit has t t l points.
Planets travel f s w they are closer to the Sun.
Th c by a line connecting the Sun and a planet rando th ut the planet's orbit.
If a planet's period of orbit increases, its radius of orbit also increas
The electromagnetic force between a planet and the Sun is what al to orbit the Sun.
Kepler's laws only apply to planets orbiting the Sun.

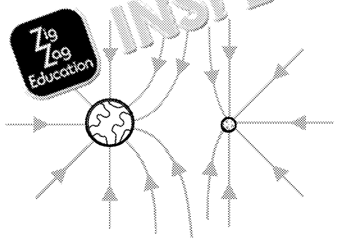
8. $T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$

$$r = \sqrt[3]{\frac{GMT^2}{4\pi^2}}$$

$$r = \sqrt[3]{\frac{(6.67 \times 10^{-11}\text{Nm}^2/\text{kg}^2)(2.0 \times 10^{30}\ \text{kg})((365 \times 24 \times 60 \times 6}{4\pi^2}}$$

$r = 1.5 \times 10^{11}$ m

9. Field lines show the ***stren*** d ection of the field at all points in
direction of the fi **ensity** of the **field lines** represents the *fi*
10.



Gravitational Fields 2 (Additional Higher Level Content)

1. $E_p = -\frac{Gm_1m_2}{r}$

   $E_p = -(6.67\times10^{-11}\,\text{Nm}^2/\text{kg}^2)\frac{(2.0\text{ kg})(6.3\text{ kg})}{(7.5\text{ m})}$

   $E_p = -1.1\times10^{-10}\text{ J}$

2. The gravitational potential energy stored between two masses is ***alwa*** at infinity. The ***closer/nearer*** two masses are, or the ***larger/greater*** their gravitational potential energy stored between the masses.

3. $v_{esc} = \sqrt{\frac{2GM}{r}}$

   $v_{esc} = \sqrt{\frac{2(6.67\times10^{-11}\,\text{Nm}^2/\text{kg}^2)(6.0\times10^{24}\text{ kg})}{(4.2\times10^{7}\text{ m})}}$

   $v_{esc} = 4.4\text{ km/s} = \sqrt{\frac{GM}{r}}$

4. $\Delta v_{orb} = \sqrt{\frac{GM}{r_f}} - \sqrt{\frac{GM}{r_i}}$

   $\Delta v_{orb} = \sqrt{\frac{(6.67\times10^{-11}\,\text{Nm}^2/\text{kg}^2)(7.3\times10^{22}\text{ kg})}{(5.4\times10^{6}\text{ m}+1.737\times10^{6}\text{ m})}} - \sqrt{\frac{(6.67\times10^{-11}\,\text{N}}{(6.5\times10^{5}}}$

   $\Delta v_{orb} = 602\text{ m/s} \approx 600\text{ m/s}$

5. The gravitational potential at a point in space is the **work done per un** infinity to that point.

6. $\Delta V_g = -G\frac{M}{r_f} - \left(-G\frac{M}{r_i}\right)$

   $\Delta V_g = GM\left(\frac{1}{r_f} - \frac{1}{r_i}\right)$

   $\Delta V_g = -(6.67\times10^{-11}\,\text{Nm}^2/\text{kg}^2)(180\text{ kg})\left(\frac{1}{760\text{ m}} - \frac{1}{750\text{ m}}\right)$

   $\Delta V_g = 2.1\times10^{-13}\text{ J/kg}$

   The change in gravitational potential is 2.1×10^{-13} J/kg. The gravitati these points is:

   $g = -\frac{\Delta V_g}{\Delta r}$

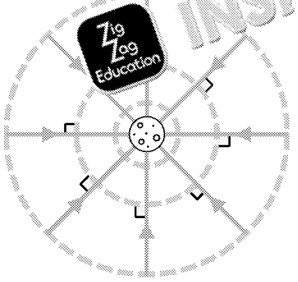
   $g = -\frac{2.1\times10^{-13}\text{ J/kg}}{760\text{ m} - 750\text{ m}}$

   $g = -2.1\times10^{-14}\text{ m/s}^2$

7. $W = m\Delta V_g$

   $W = (430\text{ kg})(78\text{ J/kg} - 65\text{ J/kg})$

   $W = 5590\text{ J} \approx 5600\text{ J}$

8. 

9. $v_{\text{orb}} = \sqrt{\frac{GM}{r}}$

$$v_{\text{orb}} = \sqrt{\frac{(6.67 \times 10^{-11} \text{Nm}^2/\text{kg}^2)(2.0 \times 10^{30} \text{ kg})}{(1.7 \times 10^{18} \text{ m})}}$$

$v_{\text{orb}} = 8.9 \text{ m/s}$

10. If a satellite is ***slower*** than the calculated orbital speed, the satellite will s
Earth's atmosphere. Earth's atmosphere exerts a ***drag*** force on all nearby
speed and fall out of orbit, but they need to accelerate every so often to s

Electric and Magnetic Fields 1

1. $F = k\frac{q_1 q_2}{r^2}$

$$F = 8.99 \times 10^9 \text{ N m}^2/\text{C}^2)\frac{(1.9 \text{ C})(1.9 \text{ C})}{(4.3 \text{ m})^2}$$

$F = 1.8 \times 10^9 \text{ N}$

The direction of the force will be along the line joining the charges, aw
charges are positive.

2. c) the force is halved

3.

Conduction	Electric charges can pass from one charged object to … are in contact.
Friction	Rubbing two objects together can cause electric cha… object and transferred to the other.
Induction	A charged object near a second object will attract ar… the object. If the charges are free to move, the se… become charged.

4. The law of conservation of electric charge states that the **total electric**
stay **constant**.

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

$$E = \frac{1.5 \times 10^{-3} \text{ N}}{1.602 \times 10^{-19} \text{ C}}$$

$E = 9.4 \times 10^{15} \text{ N/C}$

6. Objects are grounded by connecting the object to the ground with a ***co***
charge will flow to the ground, so no charge builds up in the object.

7. $\Delta V = Ed$

$\Delta V = (84 \text{ V/m})(0.18 \text{ m})$

$\Delta V = 15 \text{ V}$

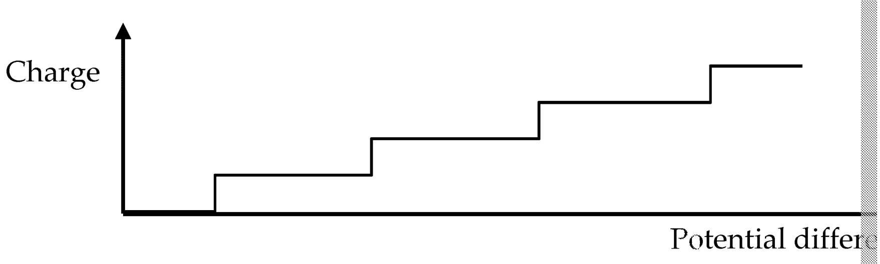
8. $\Delta V = \left(\frac{F}{q}\right) d$

$\Delta V = \left(\frac{1[illegible] \text{ N}}{[illegible] 10^{-3} \text{ C}}\right)(1.4 \text{ m})$

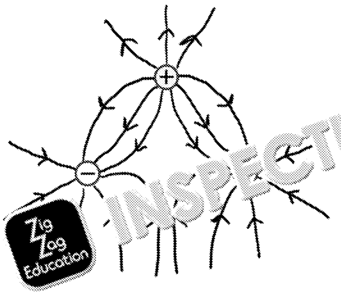
$\Delta V = 28 \text{ V}$

9.
- Millikan sprayed oil into a chamber, creating very small droplets
- Millikan also aimed an X-ray source at the chamber.
- X-rays knocked electrons out of the atoms in the oil droplets. Re charged electrons from the oil droplets left the droplets positivel
- At the top and bottom of the chamber were two parallel plates. these plates, creating a uniform electric field inside the chamber.
- The positively charged oil droplets would feel an electric force fr
- Millikan adjusted the strength of the electric field until the electr droplets was equal to the gravitational force pulling down on th the droplets to float in position inside the chamber.
- When this happened, Millikan could use the potential differenc plates to calculate the charge of each oil droplet.
- Millikan found that the charge of oil droplets did not increase st difference between his parallel plates. Instead, the electric charg that electric charge was removed from the droplets in quantised

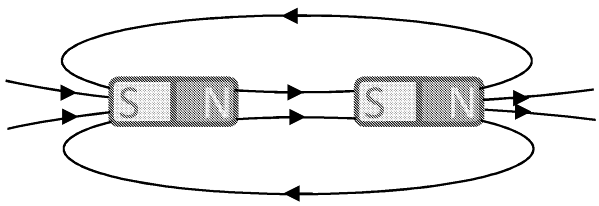
10.



11.



12.



Electric and Magnetic Fields 2 (Additional Higher Level Content)

1. $E_p = k\frac{q_1 q_2}{r}$

$E_p = (8.99 \times 10^9 \text{ N m}^2/\text{C}^2)\frac{(-7.4 \text{ C})(-7.4 \text{ C})}{(0.62 \text{ m})}$

$E_p = 7.9 \times 10^{11} \text{ J}$

2. $E_p = k\frac{q_1 q_2}{r}$

$r = k\frac{q_1 q_2}{E_p}$

$r = (8.99 \times 10^9 \text{ N m}^2/\text{C}^2)\frac{(+1.6 \times 10^{-3} \text{ C})(-7.8 \times 10^{-3} \text{ C})}{-25 \text{ J}}$

$r = 4.5 \text{ km}$

3. b) 7 eV

4. $W = q\Delta V_e$

$\Delta V_e = \frac{W}{q}$

$\Delta V_e = \frac{(25 \text{ eV}) \times (1.602 \times 10^{-19} \text{ J/eV})}{(1.602 \times 10^{-19} \text{ C})}$

$\Delta V_e = 25 \text{ V}$

5. One electronvolt is the energy it takes to move an electron across an

$2.9 \times 10^{-17} \text{ J} = \frac{2.9 \times 10^{-17} \text{ J}}{1.602 \times 10^{-19} \text{ J/eV}}$

$2.9 \times 10^{-17} \text{ J} = 181 \text{ eV}$

6. Electric fields have lines with constant electric ***potential*** called equip
Every equipotential line:

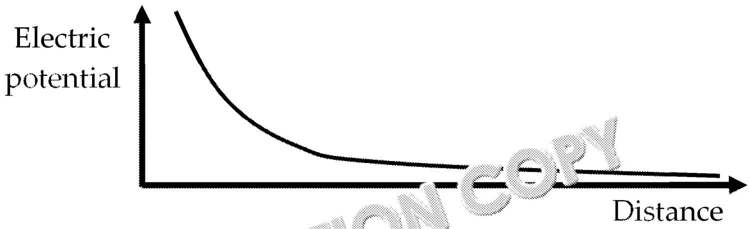
- has the ***same*** electric potential at any point along the line
- is always ***perpendicular*** to the electric field lines
- always forms a ***closed*** loop

7. $V_e = \frac{kq_1}{r}$

$V_e = (8.99 \times 10^9 \text{ N m}^2/\text{C}^2)\frac{(-1.602 \times 10^{-19} \text{ C})}{(1.5 \times 10^{-10} \text{ m})}$

$V_e = -96 \text{ mV}$

8.



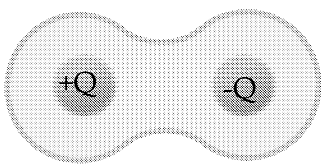
9. $W_e = -q\Delta V = -q(V_2 - V_1)$

10. $E = -\frac{\Delta V_e}{r}$

$E = -\frac{(-3.6 \text{ V})}{(1 \times 10^{-2} \text{ m})}$

$E = 360 \text{ V/m}$

11. (Third option)



Motion in Electromagnetic Fields

1. c) charge 1, 2 and 3

2.

Statement
If the charge moves perpendicular to the magnetic field, no magneti on the charge.
The magnetic force does not increase the speed of the charge.
A charge moving perpendicular to a magnetic field will follow a curv

3. The electric field exerts an electric force on any charge in the field, eve This force accelerates the charge.

4. For a charge moving through an ***electric*** field, the force acts in the dire is moving at an angle to the field, there will be a **force component** that **motion of the charge**. For a charge moving at an angle through a magn acts **perpendicular** to both the field and the **motion of the charge**. In b ***perpendicular*** to the velocity of the charge. This force acts as a **centripe** direction of the charge's ***velocity***. The field force constantly turns the c a curved, circular path.

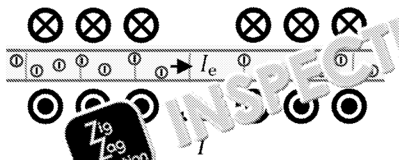
5. a) The energy of a closed isolated system must always stay constant.

6. $F_b = qvBsin\theta$

$F_b = (1.602 \times 10^{-19}\ \text{C})(3.5 \times 10^{3}\ \text{m/s})(5 \times 10^{-2}\ \text{T})\sin(60°)$

$F_b = 2.4 \times 10^{-17}\ \text{N}$

7. b) –*z* direction

8. 

(left option)

9. $F_b = BILsin\theta$

$F_b = (7.5 \times 10^{-3}\ \text{T})(0.025\ \text{A})(0.15\ \text{m})\sin(90°)$

$F_b = 2.8 \times 10^{-4}\ \text{N}$

10. $\frac{q}{m} = \frac{v}{rBsin\theta}$

$$\frac{q}{m} = \frac{(1350\ \text{m/s})}{(1.0 \times 10^{-4}\ \text{m})(0.14\ \text{T})\sin(90°)}$$

$$\frac{q}{m} = 9.6 \times 10^{7}\ \text{C/kg}$$

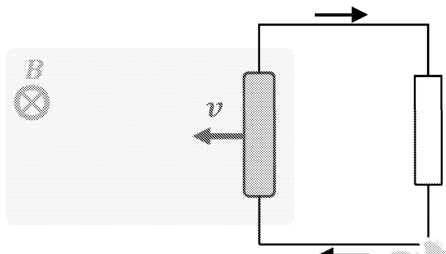
11. $\frac{F}{L} = \mu_0 \frac{I_1 I_2}{2\pi r}$

$$\frac{F}{L} = (4\pi \times 10^{-7})\frac{(1.0\ \text{A})(1.0\ \text{A})}{2\pi(0.2\ \text{m})}$$

$\frac{F}{L} = 1.0 \times 10^{-6}\ \text{N/m}$

Induction (Additional Higher Level Content)

1.



2. $\varepsilon = BvL$

$\varepsilon = (0.24\ \text{T})(0.12 \ldots)(\ldots\ \text{m})$

$\varepsilon = 1 \ldots$

3. a) $6.2 \times \ldots\ \text{Tm}^2$

4. $\Phi = BA\cos\theta$

$$B = \frac{\Phi}{A\cos\theta}$$

$$B = \frac{6.4 \times 10^{-2}\ \text{T m}^2}{(0.75\ \text{m}^2)\cos(30°)}$$

$B = 99\ \text{mT}$

5. $IR = -N\frac{\Delta\Phi}{\Delta t}$

$$I = -N\frac{(BA\cos\theta - 0)}{R\Delta t}$$

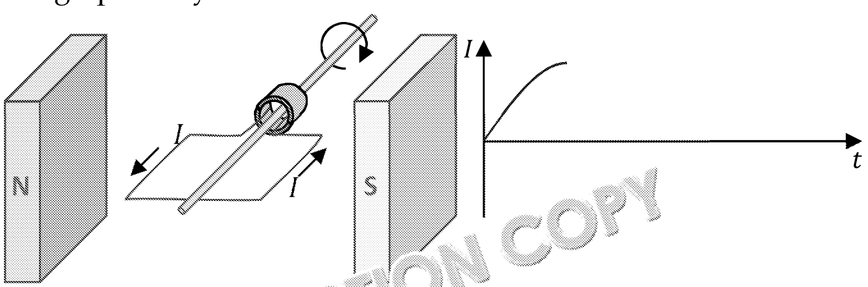
$$I = -(1)\frac{((6.0 \times 10^{-2}\ \text{T})(3.0 \times 10^{-4}\ \text{m}^2)\cos(0°) \ldots}{(30\ \Omega)(45\ \text{s})}$$

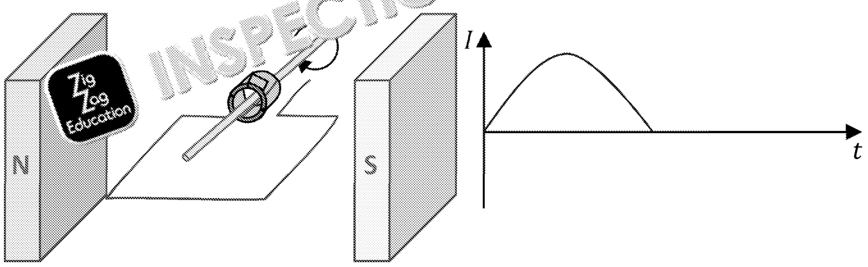
$I = -1.3 \times 10^{-8}\ \text{A}$

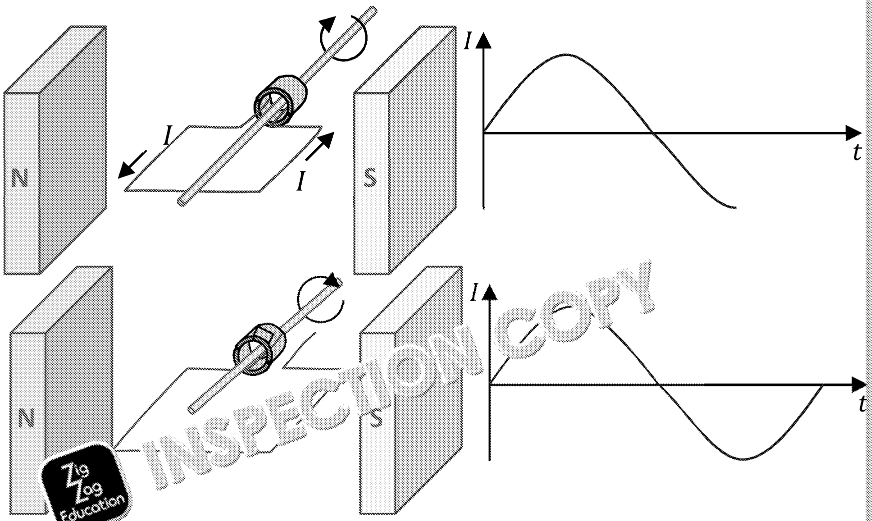
6. A coil is made ... multiple loops of a conductor. When a current fl... generates a ***magnetic*** field. The magnetic field from each loop induces ... Apply ***Lenz's*** law, this emf opposes the initial current. The magneti... emf in loop 2 that opposes the initial current, and vice versa. This self-... **changes in *electric* current** flowing through them.

7.
- The source of a magnetic field and a conductor move relative to e...
- The magnetic field from a source changes with time.

8. Mark graphs only:







9. Electric generators allow us to generate electric power from a variety burning fossil fuels, nuclear energy, or renewable resources such as w Electric generators are therefore behind the vast majority of our energ power all of our devices and machines across the world.