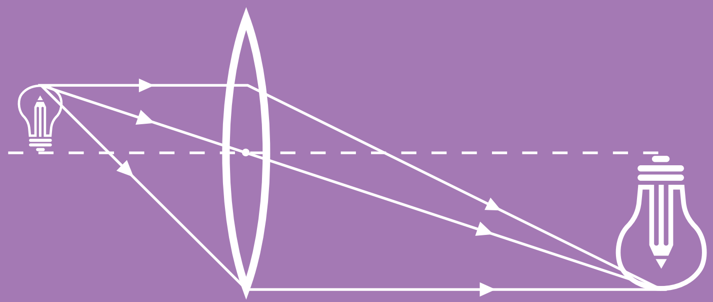
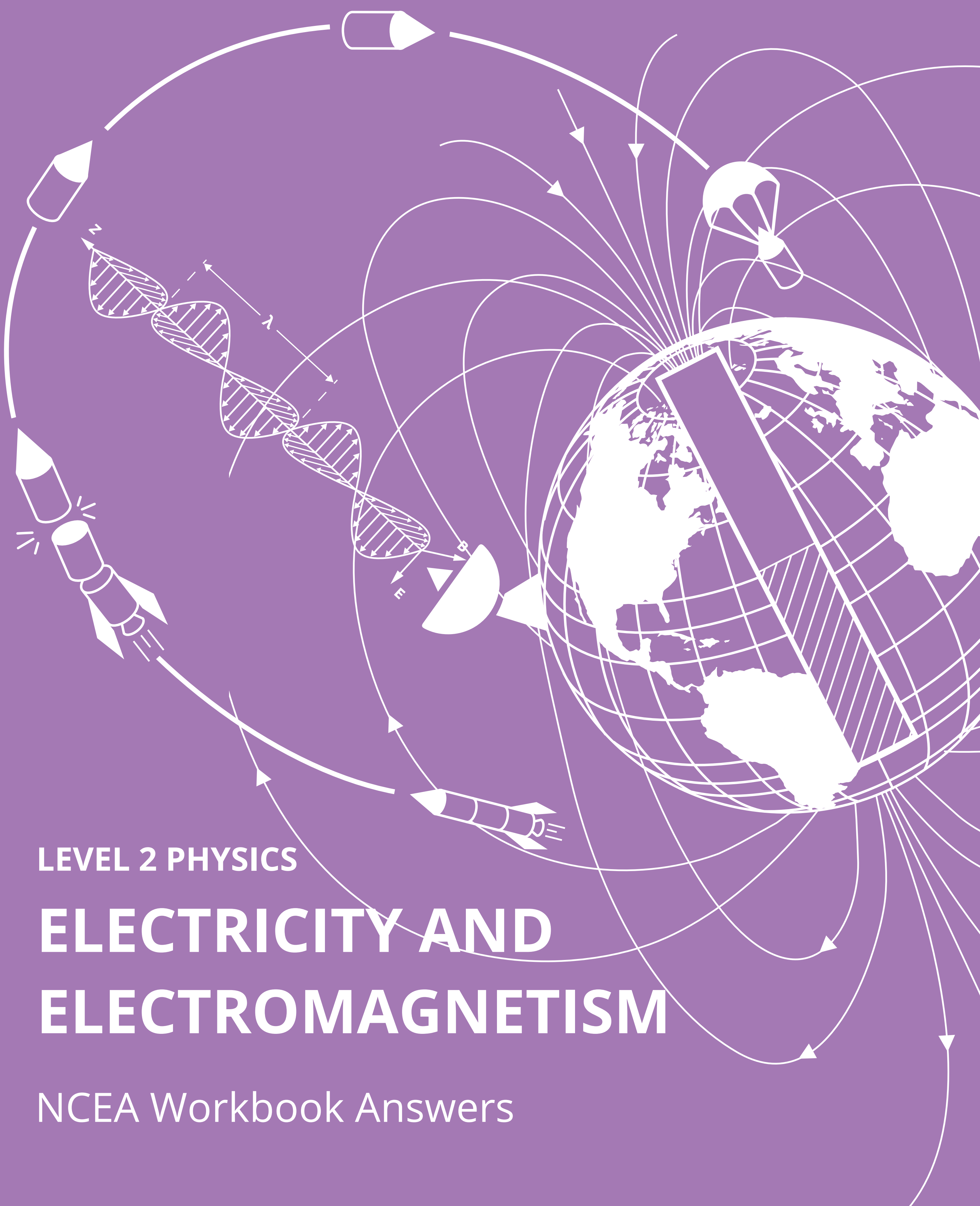


STUDY TIME



LEVEL 2 PHYSICS

ELECTRICITY AND ELECTROMAGNETISM

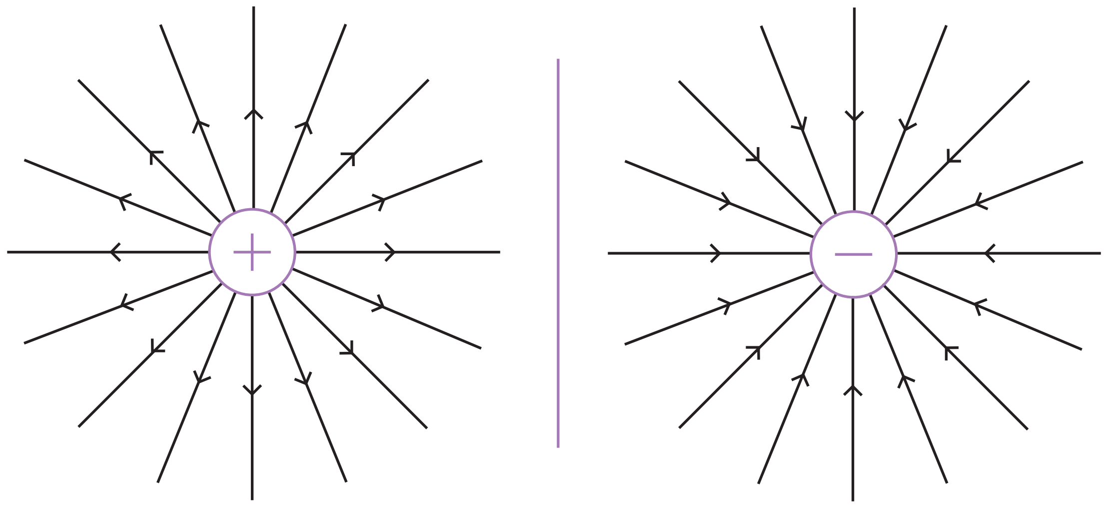
NCEA Workbook Answers

Section One
The Foundations

1. Charge

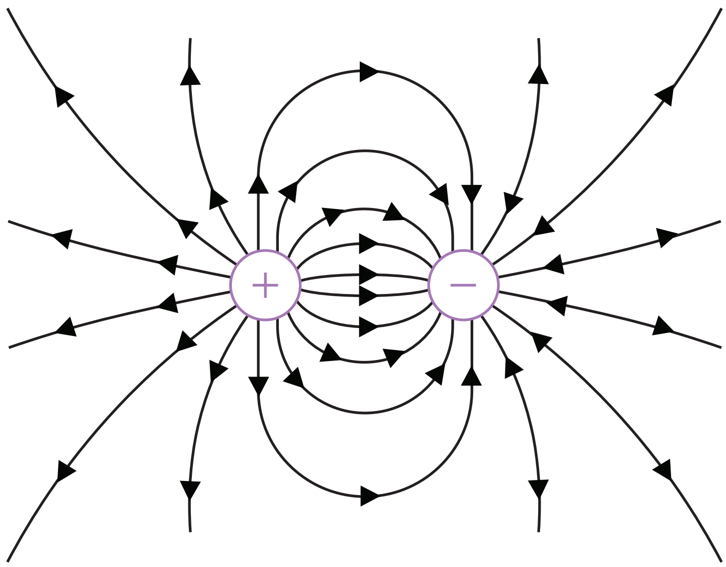
a. The unit of charge is the coulomb (C), the symbol is q.

b.



c. You should have drawn the electric field lines coming radially out of the positive charge and radially into the negative charge. Note that the strength of the electric field is the distance between the lines, so the electric field is the strongest closer to the charges and drops off the further away they get. Remember, the electric field lines show the direction that a small, positive charge would move in when placed near the positive or negative charge in the picture. A small positive charge would move away from another charge, but towards a negative charge.

d.



e. The charge on an electron is $-1.6 \times 10^{-19}\text{C}$.

f. The charge on a proton is equal and opposite to the charge on an electron, so it is $1.6 \times 10^{-19}\text{C}$.

Answers

g. We can divide the amount of charge by the charge on one electron.

$-3.8 \times 10^{-16} \div -1.6 \times 10^{-19} = 2375$. So 2375 electrons provide this amount of charge.

h. The two charge carrying particles are protons (positive charge) and electrons (negative charge).

i. *i.* A conductor is any material that is able to conduct charge, that is, charge is able to pass through it when a voltage is applied to it (or it is moving within a magnetic field, more on that later). Conductors are generally metals, which have delocalised electrons that are free to move. For example, metals such as copper and silver are good conductors.

ii. The formula for current is $I = \frac{q}{t}$ so $I = \frac{2}{8} = 0.25A$ or 0.25Cs^{-1}.

iii. Using Ohm's law, $V = IR = 0.25 \times 20 = 5V$

iv. The amount of energy lost per second in the wire is the power drawn, which is

$P = IV = 0.25 \times 5 = 1.25W$ or 1.25Js^{-1}. So the amount lost in 10 seconds is $E = Pt = 1.25 \times 10 = 12.5\text{J}$.

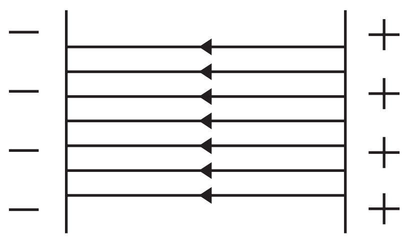
v. The energy is lost as heat.

2. Electric Fields

a. A region of space where a charged particle will experience a force. An electric field is created by a separation of charge by some distance.

b. The two units are $\frac{\text{V}}{\text{m}}$ (volts per metre) and $\frac{\text{N}}{\text{C}}$ (Newtons of force per Coloumb). These two units are exactly equivalent to each other. One describes the difference in energy between the two ends of the electric field (Vm^{-1}) and the other describes the force per coulomb that a charge in the electric field would experience.

c. A uniform electric field is one where the field strength is the same everywhere in the field. We show this with straight lines that are an equal distance away from one another.



d. The relationship for electric field strength is $E = \frac{V}{d}$. This tells us that the higher the voltage (which produces the electric field) across an electric field, the stronger the field strength.

This makes sense because voltage is a difference in potential energy, meaning that the more voltage across an electric field the more work that it is able to do and therefore the stronger the electric field.

e. The relationship for electric field strength is $E = \frac{V}{d}$. This tells us that as we decrease the distance between the two plates, the electric field strength between them increases.

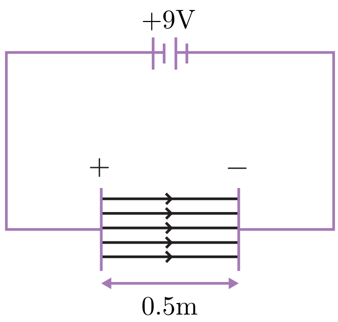
f. $\mathrm{E} = 20\mathrm{Vm}^{-1}$, $\mathrm{V} = 8\mathrm{V}$

$E = \frac{V}{d}$ which we rearrange to $\mathrm{d} = \frac{V}{E} = \frac{8}{20} = 0.4m$ or $40\mathrm{cm}$

g. *i.* The voltage across the plates is the same as the voltage of the circuit, which is 9V.

ii. $E = \frac{V}{d} = \frac{9}{0.5} = 18Vm^{-1}$

iii.



The positive terminal of the battery is on the left, so the left-hand plate will be positively charged, whereas the right terminal and plate are negatively charged. We draw electric field lines in the positive to negative direction.

h. We can use the equation $\Delta E_{\mathrm{p}} = Epd$ to calculate the electric field strength E. We first rearrange the equation for electric field strength. Remember to convert cm to the SI unit, m, before doing the calculation.

$E = \frac{\Delta E_p}{qd} = \frac{35}{2 \times 0.01} = 1750Vm^{-1}$

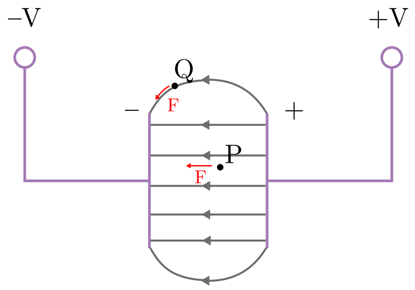
i. *i.* Electric field lines are drawn from positive to negative, they represent the direction that a positive charge would experience a force at that point. The right hand plate is positive, the left hand is negative. So the electric field lines go from right to left.

ii. The positive charge experiences a force towards the negative plate, the force vector will be parallel to the field lines. It experiences a force to the right at 0 degrees.

iii. The particle experiences a force towards the nearest negative charge, which is not directly to its right, which means it experiences a force to the right but angled downwards. This tells us that the electric field is not straight at this point.

Answers

iv.



The electric field should be straight between the plates, from left to right, because a particle between the plates experiences a force directly to the negative plate. However, the lines should be curved around the edges because a charge on the edge will experience a force that is not horizontal.

j. An electric field has electrical potential energy. The energy comes from the battery, which in turn has electric potential in the charges, which establishes a difference in potential energy across the two sides of an electric field.

This energy is then able to do work on charges within the electric field to convert the electric potential energy into kinetic energy.

k. An electric field can impart a force. An unbalanced force on something means that work is being done. In this case, the energy from the electric field does work on charged particles to impart a force that will convert electric potential energy into kinetic energy. This is a fundamental principle in physics called the Work-Energy Principle.

3. Particles in Electric Fields

a. The proton will feel a force to the left, in the direction of the electric field, as it is attracted to the unlike negative charge on the left hand plate.

b. An electron would feel a force to the right, as it is attracted to the positive plate. This is in the opposite direction to the electric field, as a negative charge will feel the opposite of a positive charge in an electric field.

c. Electric potential energy is converted into kinetic energy.

d. The energy do to work can come from a few sources. The most familiar example is from a battery, where the energy to do work will come from chemical potential energy in the battery. Another example is from a conductor moving through a magnetic field. Work is done as the conductor is moved through the magnetic field. This causes the charges to experience a force, separate, and establish an electric field.

e. A proton ($C = 1.6 \times 10^{-19}C$) moves 30cm towards the negative plate of an electric field with strength $2500Vm^{-1}$. What is the change in electric potential energy of the proton?

$\Delta E_p = Eqd$
$\Delta E_p = 2500 \times 1.6 \times 10^{-19} \times 0.3$
$\Delta E_p = 1.2 \times 10^{-16}J$

f. An electron of mass 9.12×10^{-31} kg loses 4.02×10^{-18} J of electric potential energy as it is accelerated from stationary through an electric field. What speed does it reach?

The electric potential energy lost is conserved and converted into kinetic energy:

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

$\nu = \sqrt{\frac{2E}{m}}$

$\nu = \sqrt{\frac{2 \times 4.02 \times 10^{-18}}{9.12 \times 10^{-31}}}$

$\nu = 2970000ms^{-1}$ ($3SF$)

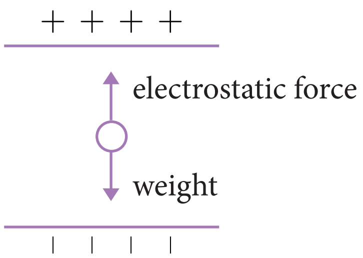
g. A certain drop of oil has a charge of -1.60×10^{-12} C. How much force is exerted on the oil drop by an electric field with strength $12.0\ Vm^{-1}$?

$F = Eq$
$F = 12 \times 1.6 \times 10^{-12}$
$F = 1.92 \times 10^{-11}\ NC^{-1}$

Electric Fields in Context

h. Weight (force due to gravity) and electrostatic force (the force on the charge due to the electric field between the cathode and the anode).

i. Draw arrows on the diagram indicating the size and direction of these two forces. Explain your answer.



The arrow indicating weight force should point upwards, and the arrow indicating electrostatic force should point down. Both arrows should be the same length.

j. Weight force always acts in a downwards direction. The oil drop is negatively charged so it will feel an electrostatic force upwards towards the positive plate. In order for the drop to remain stationary (no acceleration), the two opposing forces must cancel each other out exactly, so they must be the same size.

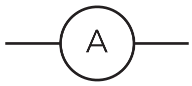
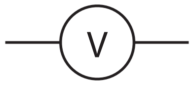
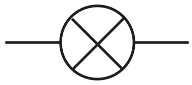
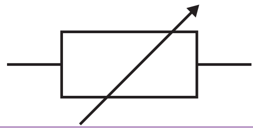
4. Introduction to DC Circuits

a. Voltage is the difference in electric potential between two points in a circuit. It is quantified as the amount of energy per charge, so it is measured in joules per coulomb (JC^{-1}), otherwise known as volts (V).

b. Resistance is a material or component's opposition to the flow of electric current, measured in ohms (Ω).

c. Current is the rate of flow of charge through a conductor, measured in amperes (A). One ampere is the flow of one coulomb of charge per second.

d.

Name	Symbol	Function
Ammeter		Measures the current at a certain point in a circuit.
Voltmeter		Measures the voltage drop across a section of a circuit.
Lamp		Lights up when a current is run through it.
Resistor		Opposes the current in a circuit, controls the flow of current to the other components.
Switch		Opens and closes a branch of a circuit, turning the current on and off.
Cell		Single unit that converts chemical energy into electrical energy.
Variable resistor		A resistor where the resistance value can be adjusted.
Battery		A collection of cells that provides a source of electrical energy for a circuit.

e.

The right side is the positive terminal

f. From the negative terminal around the circuit to the positive terminal. They are repelled from the negative terminal as similar charges repel, and attracted to the oppositely charged positive terminal.

g. From the positive terminal of the battery to the negative terminal (conventional current is the flow of positive charge, so it is opposite to the electron flow).

h. V = IR

The voltage (V) over a component in a circuit is equal to the current flowing through it (I) multiplied by its resistance (R).

i. *i.* $V = IR = 6 \times 3 = 18V$

ii. Make sure you convert to decimal or scientific notation.

$V = IR = 0.003 \times 2000 = 6V$

iii. Rearrange Ohm's law to get:
$I = \frac{V}{R} = \frac{12}{24} = 0.5A$

iv. Make sure to convert to decimal or scientific notation and rearrange Ohm's law to get:

$\mathrm{I} = \frac{V}{R} = \frac{10}{500} = 0.02A = 20\mathrm{m}A$

v. First convert to decimal or scientific notation and rearrange Ohm's law.

$\mathrm{R} = \frac{V}{I} = \frac{2}{0.025} = 80\ \Omega$

vi. First convert to decimal or scientific notation and rearrange Ohm's law.

$\mathrm{R} = \frac{V}{I} = \frac{35000}{20} = 1750\ \Omega$

5. Voltage and Current

a. *i.* A battery has chemical potential energy, which comes from chemical reactions that take place inside the battery.

ii. The charge has electric potential energy, in exactly the same way as a charged particle in an electric field has electric potential energy. This is exactly what voltage is: the amount of potential energy that the charge has.

iii. The charge moves! It experiences a force, which causes it to move within the wire. All of the charges experience this force at pretty much the same time, and so all of the charges in the wire move through the wire.

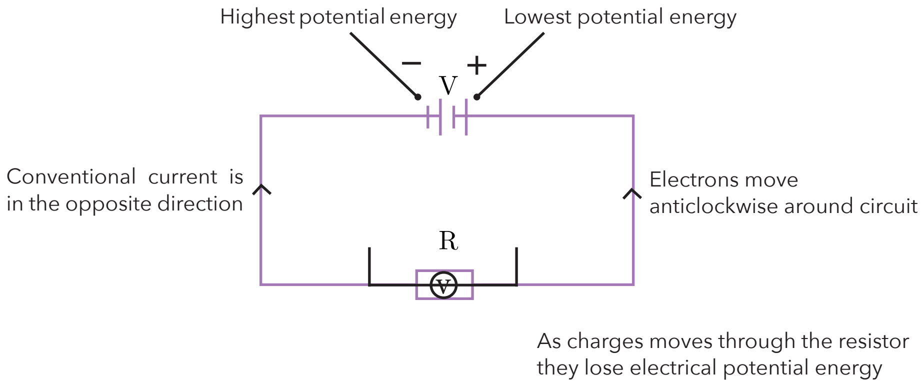
iv. The electric potential energy is converted into another form. In the case of a resistor, the energy of the charges is lost as heat in the resistor. In the case of a bulb, the energy of the charges is lost as heat and light.

v. A battery provides chemical potential energy to charges in a circuit. This chemical potential energy does work on the charges to create a current. As the charges move through the circuit, their energy is lost through the components as other forms of energy. Due to conservation of energy, all of the energy must be lost to other forms of energy as they move through the circuit. This means that the potential energy of charges at the other terminal of the cell is 0.

b. Explain how a voltage generates a current in a closed circuit. In your answer you should discuss thepotential energy and work done on charges.

A voltage is a difference in potential energy between the terminals of the battery. This is the energy that does work on the charges in the circuit. This causes charges in the circuit to experience a force (known as the electromotive force) that moves them through the circuit. You can think of this like a ball rolling down a hill. The charges 'want' to go from high potential energy to low potential energy, just like a ball at the top of a hill.

c.



i. The electrons will move from high potential energy at the negative terminal to low potential energy at the positive terminal. This means that the electrons will be moving anticlockwise around this circuit.

ii. This means that conventional current will move in the clockwise direction, because it is the opposite of electron flow.

iii. They will lose their potential energy and, assuming that the wire in this circuit has no resistance, they will lose all of their potential energy through the one resistor.

d. *i.* JC^{-1} is the same as voltage, so the voltage of the battery is 6 V.

ii. As all energy must be lost through the circuit, they will lose 4 JC^{-1} of energy.

iii. Resistor B must have twice as much resistance, because the charges lose twice as much energy through resistor B. Therefore it must have a resistance of 40Ω.

iv. Using Ohm's law $V = IR$, the total voltage is 6 V and the total resistance is $20 + 40 = 60\ \Omega$

So, the current is $I = \frac{V}{R} = \frac{6}{60} = 0.1A$

v. The current in the circuit is 0.1 A, which means that through any point there are 0.1 coulombs of charge passing through that point per second. Therefore, in 4 seconds, 0.4 coulombs of charge pass through point P, or any other point in the circuit.

$q = It \ = 0.1 \times 4 \ = 0.4C$

e. *i.* The resistance of an ideal ammeter is zero.

ii. If the ammeter has a resistance, it will influence the current in the circuit, giving an inaccurate reading.

iii. We can use Ohm's law. $V = IR = 2 \times 3 = 6\ V$

f. *i.* The resistance of an ideal voltmeter is infinite

ii. In parallel.

iii. If there is any current flowing through the voltmeter, it will change the reading, so the voltmeter must have a very, very high resistance so that no current flows through it.

iv. The voltmeter is connected to the terminals of the battery, meaning that it is measuring the voltage of the whole circuit. Therefore we can use Ohm's law to calculate the current.

$I = \frac{V}{R} = \frac{6}{18} = 0.33\ A\ (2\ d.p.)$

6. Series and Parallel Circuits

a. The current is only able to take one path, therefore at all points in the circuit the current will be the same. This is because all of the charges in the circuit will experience the same resistance to their flow; regardless of where they are in the circuit.

b. The current flowing through paths connected in parallel will depend on the resistance of those branches, therefore the current may be different. However, when the currents meets at a junction (the point where the branches split off), it will combine to the total current in the circuit.

c. *i.* The resistors R_A, R_B and R_C are all in series with one another. They are all in series with the battery.

ii. The resistors R_A, R_B and R_C are all in parallel with each other. They are in series with the battery.

Answers

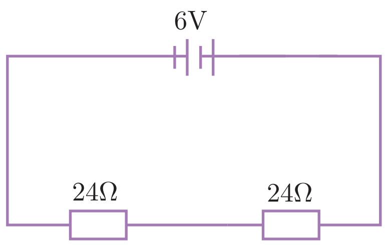
iii. The resistors R_A and R_B are connected in parallel with one another and R_C is connected in series to them. They are connected in series to the power supply.

iv. The resistors R_A, R_B and R_C are all in series with one another. They are all in series with the battery.

v. The resistors R_A, R_B and R_C are connected in parallel to one another. They are connected in series to R_D and the battery.

vi. The resistors R_B and R_C are connected in parallel to one another. They are connected in series to resistor R_A, bulb B_A and the battery.

d. *i.*



ii. This is a series circuit, so we use $R_T = R_1 + R_2$ to calculate the total resistance, which is $R_T = 24 + 24 = 48\Omega$.

iii. The voltage across each resistor will be 3V.

The total voltage across the circuit is 6V and the resistors are identical, which means they will have the same voltage across them. The voltage will split evenly across the resistors, meaning they will have 3V across them.

iv. V = IR so $I = \frac{V}{R_T} = \frac{6}{48} = 0.125A$

e. *i.* The voltage across each branch is the same as the voltage of the power supply, which is 10V. This is the rule that voltage stays the same in parallel.

ii. The current splits in parallel circuits, and because the bulbs are identical (they have the same resistance), the current will split evenly across each of the branches. This means that the current at point P is twice the current at point Q.

iii. Note: This question has been updated slightly in newer versions of the workbook where 'bulb 2' is replaced with 'bulb A'. Revised question is provided below in blue:

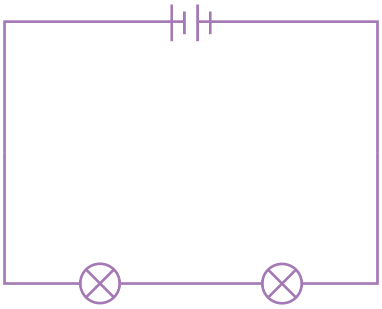
If bulb A blows, what will happen to the current at point P compared to point Q? Explain your answer.

If bulb A blows, the current will no longer be able to travel through the branch with bulb A on it. This will mean that all of the current will now flow through the branch with point Q on it, which means the current at point P will be the same as at point Q. In fact, all of the points on the circuit will now have the same current.

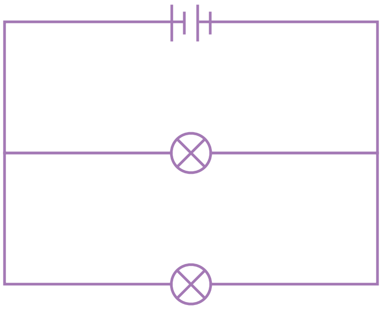
f. A series circuit has its components all wired around one 'loop' - there is only one path for the current to take. A parallel circuit has multiple loops and therefore multiple possible pathways for current to flow.

Example diagrams (your diagrams may look slightly different - your series circuit should only have one loop, and the parallel circuit multiple).

Series circuit:



Parallel circuit:



7. Resistance

a. Resistance is the ability for something to oppose current from moving through it. The higher the resistance, the more it is able to oppose current from moving through it (which means the current does more work to get through the resistor) and therefore the more energy charges lose moving through the component.

b. $R = V/I$

c. What is the resistance of a bulb that has a voltage of 0.18V when a current of 4.5mA runs through it?

$R = V/I$
$R = 0.18/0.0045$
$R = 40\Omega$

d. Materials with a very low resistance are called electrical conductors. Electrical current can flow very easily through conductors, meaning that conductors such as metals, are ideal for making circuits.

e. $R = V/I$
$R = 12/0.4$
$R = 30\Omega$

f. The three bulbs in series add to give a total resistance of 30Ω:
$30/3 = 10\Omega$

g. There are now more paths for the current to flow through, so the total resistance of the circuit decreases.

h. Resistance of upper branch: $R_T = 10 + 10 + 10 = 30\Omega$

Resistance of lower branch: R_T=10Ω

$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{30} + \frac{1}{10} = \frac{2}{15}$

$\frac{1}{R_T} = \frac{2}{15}$

$R_T = \frac{15}{2} = 7.5\Omega$

i. Resistance of loop:

$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{5} + \frac{1}{7} + \frac{1}{7} = \frac{17}{35}$

$\frac{1}{R_1} = \frac{17}{35} = 0.4857...$

$\mathrm{RT} = \frac{35}{17} = 2.05\Omega$

Total resistance:

$10 + 2.05 = 10.05\Omega$

$= 10.1\Omega\ (3\text{s.f.})$

8. Power

a. Power is the rate at which energy is transferred or converted (e.g. the rate at which a lamp converts electrical energy to heat and light). It is measured in joules per second, known as watts (W).

b. $V = IR$ so replacing voltage in $P = IV$

$P = I(IR)$

$P = I^2R$

c. $V = IR$

$I = V/R$ so replacing current in $P = IV$

$P = (\frac{V}{R})V$

$P = V^2/R$

d. $P = IV$

Therefore $I = \frac{P}{V} = \frac{60}{240} = 0.25\text{A}$

e. $V = IR$

$V = 1.5 \times 5$

$V = 7.5V$

$P = \text{IV}$

$P = 1.5 \times 7.5$

$P = 11.25W$

f. The power of the 2V bulb is $P = \text{IV} = 0.4 \times 2 = 0.8\text{W}.$

The power of the 3V bulb is $P = \text{IV} = 0.4 \times 3 = 1.2\text{W}.$

g. The 3V bulb will be brighter, as it has a higher power. The brightness of a bulb is proportional to its power. An increased power means an increased rate of energy output, and therefore more light is emitted per second.

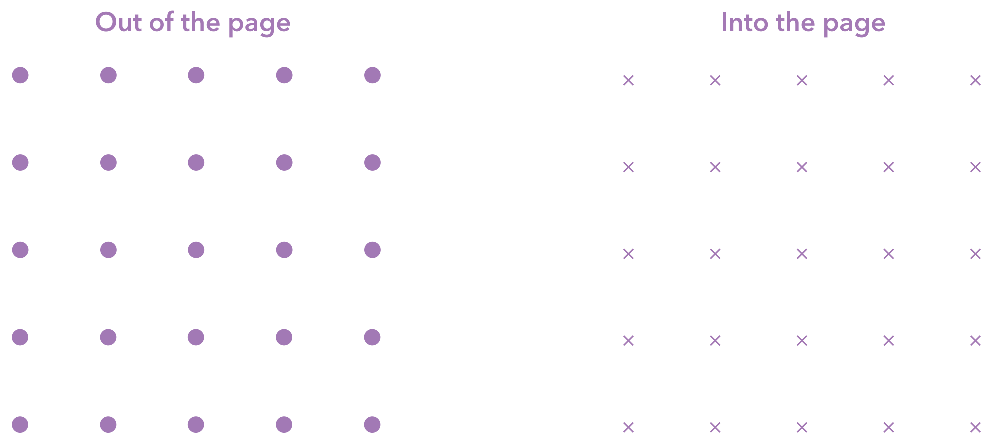
9. Magnetic Fields and Moving Charge

Magnetic Fields

a. A magnetic field is a region where moving charges or magnetic objects will experience a force. Magnetic fields come from either ferromagnetic materials like iron, or from charges that are moving.

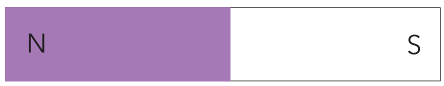
b. The unit for magnetic field strength is Teslas (T), named after Nikola Tesla. The symbol for magnetic field strength is B.

c.

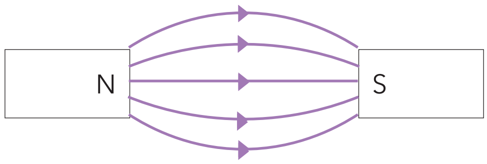


We represent a magnetic field going out of the page as dots. Make sure that these are equally spaced for a uniform magnetic field. We represent a magnetic field going into the page as an x. Again, make sure the x's are equally spaced. This is often described as the tip and tail of an arrow flying at you. If it's flying away you will see the cross of the feathers and if it's flying towards you you will see the arrow tip (hopefully you never have to experience this one!)

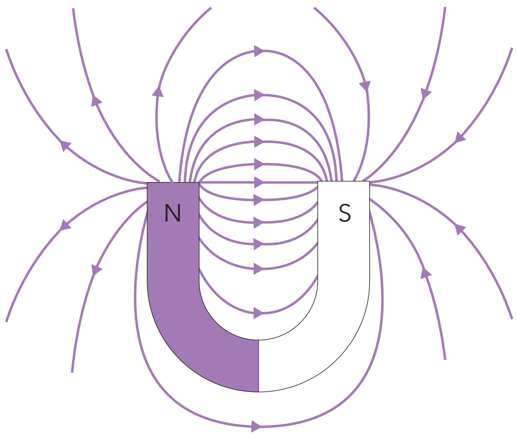
d. *i.*



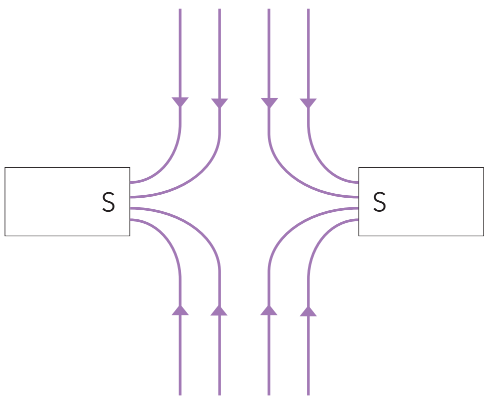
ii.



iii.



iv.



e. The stronger a magnetic field, the closer the field lines are to one another. This is known as the density of the magnetic field.

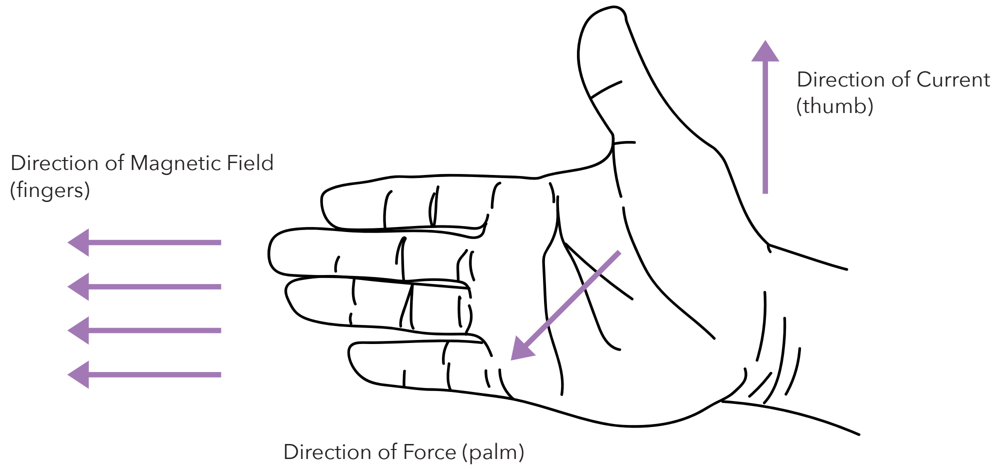
Charges and Magnetic Fields

f. *i.*

ii. A Direction: clockwise / counterclockwise   B Direction: clockwise / counterclockwise

iii. When charge is moving, as in a wire with a current running through it, a magnetic field is created. The right hand grip rule is used to determine the direction of the magnetic field. Our thumb points in the direction of the conventional current, and our fingers point in the direction of the magnetic field.

g.



h. Formula: $F = Bqv$

i. As the size of the charge increases, with everything else staying the same, the amount of force experienced will increase.

ii. As the velocity of a charge increases, with everything else staying the same, the amount of force experienced will increase.

iii. As the strength of the magnetic field increases, with everything else staying the same, the amount of force experienced will increase.

i. *i.* The right hand slap rule tells us the direction that a positive charge will experience a force (the amount of force experienced by a negative charge is equal and opposite to this force).

ii. We use $F = Bqv$ to calculate the size of the force. We first make sure to write what we're given down and convert to decimal or scientific notation.

$F = 15 \times 10^{-3} \times 0.2 \times 150 = 0.45N$

Using the right hand slap rule, the magnetic field lines are going into the page, the velocity is to the right, so the direction of the force is upwards.

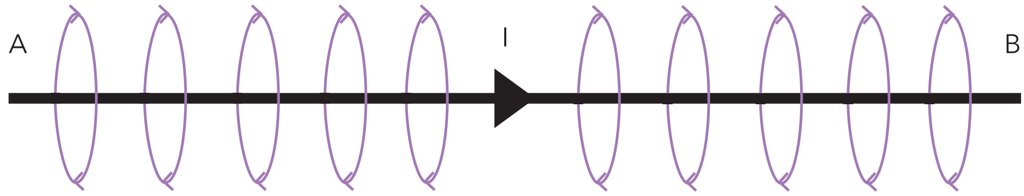
iii. The size of the force experienced by a moving charge in a magnetic field is proportional to its velocity. We can write this as:

$F \alpha \text{ v}$

So if the velocity is halved for instance, so will the force that it experiences.

iv. It will not experience a force. A moving charge must be moving at an angle to the field lines to experience a force; in NCEA Physics, this will always be at a right angle to the magnetic field lines.

j.



i.

k. i. We can use Ohm's law to calculate the current. We rearrange for current and plug in the values we are given.

$I = \frac{V}{R} = \frac{6}{2} = 3A$

ii. The conventional current flows from the positive terminal to the negative terminal. Therefore the direction of conventional current will be from left to right in the wire that is passing through the magnetic field. It will be in an anticlockwise direction for the whole circuit.

The magnetic field is coming out of the page.

iii. We use the right hand slap rule to determine the direction of the force. The magnetic field is coming out of the page. The conventional current is from left to right. Therefore the charges experience a force in the downwards direction.

iv. The length of the wire on the bottom of the circuit is 50cm but the magnetic field is 30cm wide, so only 30cm of the wire passes through the magnetic field.

v. We use the formula $F = BIL$ to calculate the size of the force. We must be careful to convert to SI units. Here, F= force, B is still the magnetic field strength, I is still the amount of current, and L is the length of the wire in the magnetic field.

$F = BIL = 0.2 \times 3 \times 0.3 = 0.18N$

The direction of this force is downwards.

10. Electromagnetism and Induced Voltage

a. A conductive wire has delocalised electrons, which are charged particles that are free to move, inside it. When we move the wire through the magnetic field perpendicular to the field lines, we are essentially moving these delocalised electrons through the magnetic field, since they are inside the wire. This means the electrons (charged particles) experience a component of force perpendicular to both the magnetic field and their direction of motion. This component of force pushes them down the wire, since they are free to move, and this means they all accumulate towards one end of the conductor. This creates a separation fo charge, since one end of the wire now has more electrons than the other end. This separation of charge is a voltage.

b. Only electrons are able to move inside a conductor.

c. i. Current can be calculated using $I = \frac{q}{t} = 0.2A$. Conventional current is right to left.

ii. We use Ohm's law to calculate the size of the current, which is:

$I = \frac{V}{R} = \frac{12}{6} = 2A$

The direction is to the right, as the positive terminal is on the right and conventional current flows from high positive potential to low positive potential.

iii. The size of the force can be calculated using $F = BIL$. We have been given B and L and have just calculated I.

$F = 0.250 \times 2 \times 0.15 = 0.075 = 0.075N\ (3s.f.)$

iv. We use the right-hand slap rule to determine the direction of the force, which is perpendicular to conventional current and the magnetic field. The conventional current is to the right, the magnetic field is into the page, so the force is upwards.

This is because the charges experience a force when moving inside a magnetic field (or more accurately the electrons experience a force while moving). The magnetic field does work on these moving charges.

d. Formula: $V = B\mathrm{v}L$

i. As the length increases, so will the induced voltage. This is because in a larger length of wire there are more charges that are available to experience a force and thus the greater the separation of charge, increasing the induced voltage.

$V \alpha\, L$

ii. As the magnetic field strength increases, the induced voltage will also increase. When charges move through a stronger magnetic field, the charges in a conductor will have more work done on them, increasing the force they experience and therefore increasing the separation of charge.

$V \alpha\, B$

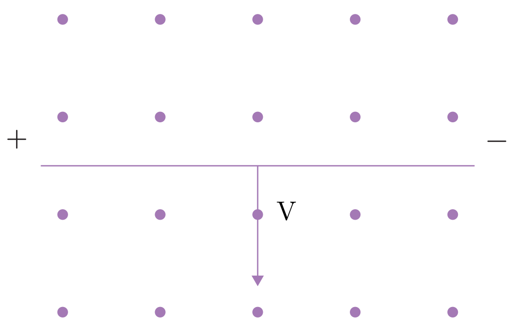
iii. When a conductor has a greater velocity through a magnetic field, more work must be done to do so, meaning that the induced voltage is greater. The faster they are moving through the magnetic field, the greater the force they experience and therefore the greater the separation of charge, meaning a larger induced voltage.

$V \alpha\, \mathrm{v}$

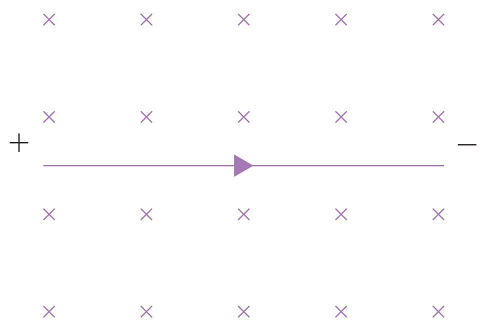
e. *i.* The force on a conductor moving through magnetic field is described by $F = Bq\mathrm{v}$. The only difference between these three situations is the component of its velocity that is at a right angle to the magnetic field. In situation A, only part of the rod's (and therefore the charges in the rod) velocity is at a right angle, because it is travelling at a 50° to the horizontal. In situation B, all of the rod's velocity is at a right angle to the magnetic field lines and in situation C, none of the rod's velocity is at a right angle to the field lines. Therefore the force will be largest in situation B, smallest in situation C and then the force in situation A will be somewhere between the two.

ii. Similar to the previous answer, the induced voltage is described by $V = B\mathrm{v}L$. The only difference between the situations is the component of velocity that is at a right angle to the magnetic field lines. It will follow the same pattern. Situation B will produce the largest induced voltage. Situation C will not produce a voltage and situation A will have an induced voltage somewhere between the two.

f. *i.*

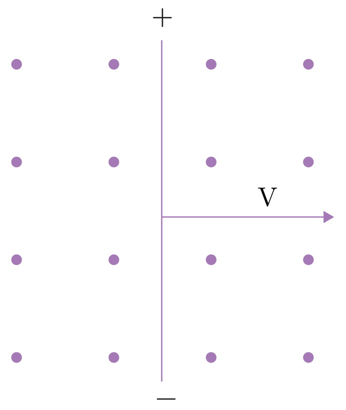


ii.



Force: 0.05N
Direction: Up

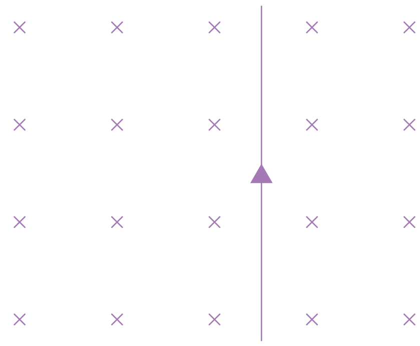
iii.



Voltage: 1.2V

Direction: Up

iv.



Force: 3×10^{-3}N

Direction: Left

g. *i.* The current is determined by the voltage and resistance. Using Ohm's law:

$R = \frac{V}{I} = \frac{12}{0.2} = 60\Omega$

ii. Electrons will move from the negative terminal to the positive. So electron flow is clockwise, therefore conventional current is anticlockwise.

iii. Conventional current is to the right, the magnetic field is going into the page, therefore the force experienced by the positive charges using the right hand slap rule is going in the upwards direction.

The size of the force is given by:

$F = BIL$ where B = 0.5T, I = 0.2A and L = 0.25m

Therefore the force experienced is going to be:

$F = 0.5 \times 0.2 \text{ x } 0.25 = 0.025N$

iv. Voltage remains the same, but the resistance is reduced, so the new current is:

$I = \frac{V}{R} = \frac{12}{6} = 2A$

v. $F = BIL$

$F = 0.5 \text{ x } 2 \text{ x } 0.25 = 0.25N$

Answers

Section Two
Exam Skills & Mixed Practice

1. Static Electricity and Electric Fields

Holtz Influence Machine

a. *i.* Write down the information given in the question.

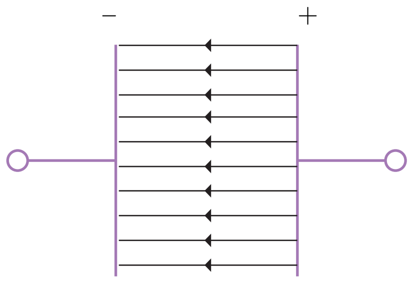
We've been given the voltage and distance across the plates.
$V = 15000V$ $\quad\quad d = 0.30m$

ii. We use the equation $E = \frac{V}{d}$ and plug in the values we are given.

$$E = \frac{V}{d} = \frac{15000}{0.3} = 50000Vm^{-1}$$

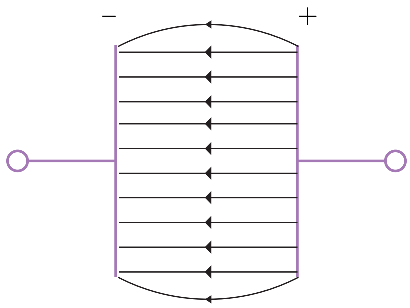
b. *i.* From the positive plate to the negative plate. The direction that a positive charge would experience a force.

ii.



iii. No, outside the boundary the electric field is not uniform.

iv.



c. *i.* Electric potential energy is converted into kinetic energy as work is done on the electron by an electric field.

ii. Calculate the electric potential energy of an electron at the negative plate.

We use the equation $Ep = Eqd$ and substitute in the values for these.

$$Ep = 50000 \times 1.6 \times 10^{-19} \times 0.3 = 2.4 \times 10^{-15}J$$

iii. Assuming conservation of energy, $E_{k\ (gained)} = E_{p\ (lost)}$ which means that the electron will have $2.4 \times 10^{-15} J$ of energy as it reaches the positive plate. In other words, the electric field has done this amount of work.

$$E_k = 2.4 \times 10^{-15} J$$

iv. Starting with $E_k = ½mv^2$:

$2E_k = mv^2$ Multiply both sides by 2

$\frac{2E_k}{m} = v^2$ Divide both sides by m

$\sqrt{2Ekm} = v$ Square root both sides

v. Now we can just solve the equation, using the mass of an electron.

$$v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2 \times 2.4 \times 10^{-15}}{9.11 \times 10^{-31}}} = 72591415.94 = 72600000 ms^{-1}$$

d. i. $F = 0.25 \times 9.8 = 2.45N$

ii. The forces acting on the ball must be balanced for it to be stationary. Therefore $F_{net} = 0$.

iii. Because the gravitational force is acting downwards, the electric force must be acting upwards. It must be equal to the size of the gravitational force. So the force from the electric field must be 2.45 N.

iv. We will use the equation $F = Eq$. We know the strength of the electric field is 50000Vm^{-1} and the force we know to be 2.45N.

v. $q = \frac{F}{E} = \frac{2.45}{50000} = 4.9 \times 10^{-5} C$ (make sure to include Coulomb as the unit)

The electric force is upwards, and the positive plate is on top, so for the ball to experience a force towards the positive plate, it must have a negative charge.

A Ball in An Electric Field

a. If the distance between the plates is 2cm, show that the voltage supplied is 16V.

a. i. We have been given distance and electric field strength.

$d = 0.02\ m$ $E = 800Vm^{-1}$

ii. We use the equation $E = \frac{V}{d}$ and rearrange for the voltage.

$$V = Ed = 800 \times 0.02 = 16V$$

b. i. They travel from the positive plate to the negative plate, which is the direction that a positive charge in the field would experience a force.

ii. The left end will be negative because the field lines are travelling towards it.

c. *i.* Electric potential energy to kinetic energy.

ii. It has kinetic energy because it is moving. It has lost all of its electric potential energy because it is 0m from the plate.

We use $E_k = \frac{1}{2} mv^2$ and plug in the values given.

$E_k = \frac{1}{2} \times 0.1 \times 0.5^2 = 0.0125J$

iii. $E_{k(gained)} = E_{p(lost)}$ So the object would have had 0.0125J of electric potential energy at the negative plate.

This is assuming that no energy is lost to friction due to moving through the air (we are told that the slider is frictionless so this is not an assumption).

iv. $E_p = Eqd$ and rearrange for charge.

$q = \frac{E_p}{Ed} = \frac{0.0125}{800 \times 0.02} = 7.8125 \times 10^{-4} = 7.81 \times 10^{-4}C$ but because it must have a negative charge this is $-7.81 \times 10^{-4}C$

d. *i.* The new voltage is 32V, which is double the previous voltage because Eru adds another 16V power supply in series with the existing 16V power supply. If this was the only change the electric field strength will double because $E \propto V$.

ii. The new plate separation is 4cm, if this is the only change the electric field strength will halve. This is because $E \propto \frac{1}{d}$.

iii. The potential energy of the object depends on its charge, the distance it will travel and the electric field strength. $\Delta Ep = Eqd$.

iv. Assuming energy is conserved, the electric potential energy will be converted to kinetic energy as the electric field does work on the charges.

$E_{p(lost)} = E_{k(gained)}$

v. The voltage and distance have both doubled. However, electric field strength is proportional to the voltage but inversely proportional to the plate separation, so the electric field strength does not change. Therefore the amount of electric potential energy gained by the object remains the same. This means that the same amount of kinetic energy is gained by the object. Overall there is no change to the speed that the object reaches in the electric field.

Electron Beam Welder

a. *i.* We've been given the voltage across the plates which is 140000V and the distance which is 0.0002m.

ii. $E = \frac{V}{d} = \frac{140000}{0.0002} = 700000000Vm^{-1}$

iii. The prefix Mega is 1000000 (1 million) or 10^6 so we can divide our result by 10^6 to convert to megavolts per metre.

$E = \frac{700 \times 10^6}{10^6} = 700MVm^{-1}$

b. i. According to the formula $F = Eq$, the force does not depend on where in the electric field the charge is. It only depends on the size of the charge and the strength of the electric field.

ii. $F = Eq$ so $F = 700 \times 10^6 \times -1.6 \times 10^{-19} = -1.12 \times 10^{-10}N$

Also, you don't have to include the negative, but it helps to understand the direction of the force, which is in the opposite direction to the field lines (direction of force on a positive charge).

iii. An electron has a negative charge, which in this case will cause it to experience a force towards the anode (the positive plate). This is in the downwards direction.

c. i. It depends on the strength of the electric field and the size of the charge. This means that the distance it has travelled does not change the force it experiences.

ii. It does not affect the force on the electron.

Answers

d. i. Electric potential energy into kinetic energy.

ii. We know the charge on an electron, the distance it travels, and the electric field strength. So we can just plug in the values.

$E_p = Eqd = 700 \times 10^6 \times 1.6 \times 10^{-19} \times 0.0002 = 2.24 \times 10^{-14}J$

iii. The electron will have kinetic energy equal to the amount of potential energy it had at the negative plate. By conservation of energy $E_{k(gained)} = E_{p(lost)}$.

$E_k = 2.24 \times 10^{-14}J$

iv. $2E_k = mv2$ Multiply both sides by 2

$\frac{2E_k}{m} = v2$ Divide both sides by m

$\sqrt{\frac{2E_k}{m}} = v$ Square root both sides

$v = \sqrt{\frac{2 \times 2.24 \times 10^{-14}}{9.11 \times 10^{-31}}} = 222000000ms^{-1}$

v. The electron beam welder is accelerating the electrons to near the speed of light! This is incredible really, and indeed EBW do accelerate electrons to roughly 70% of the speed of light. We used accurate information about these machines (although they are a bit more complicated than we have described), which tells you that the stuff you learn in this standard is pretty relevant!

e. *i.* The magnetic field on the left is coming out of the page, and the magnetic field on the right is going into the page.

ii. Electrons that pass through the left hand magnetic field are travelling downwards and experience a force in the opposite direction to a positive charge, which means they experience a force to the right. Electrons that pass through the right hand magnetic field are also travelling downwards, but this magnetic field is coming out of the page, so they experience a force to the left instead.

iii. Electrons passing through the right hand field will experience a force to the left ,while those passing through the left hand side experience a force to the right. This means that their paths will curve towards the center regardless of whether they go through the left hand field or the right hand field.

iv. The magnetic field of the lens has an opposite direction either side of the central path. These magnetic fields apply a force on electrons that is always towards the center. The overall effect of this is that electrons are concentrated/clustered/moved to the center of the magnetic lens. This makes the electrons more likely to hit a single point.

Van de Graff Generator

a. *i.* We are given electric field strength $\mathrm{E} = 80000\mathrm{Vm}^{-1}$ and voltage $\mathrm{V} = 20000\mathrm{V}$.

ii. We use the equation $E = \frac{V}{d}$ and rearrange for distance.

$d = \frac{V}{E} = \frac{20000}{80000} = 0.25m = 25cm$

b. *i.* The distance between any field lines in a uniform magnetic field is the same.

ii. The field lines in the diagram are equally spaced, therefore the electric field is uniform.

c. *i.* It only depends on the electric field strength and the size of the charge.

F = Eq

ii. A proton has a charge of 1.6×10^{-19}C and an electron has a charge of -1.6×10^{-19}C.

iii. The electric field strength is the same everywhere, and the charges have equal but opposite size. Therefore they will have an equal and opposite force acting on them.

Answers

d. *i.* The charges are equal and opposite.

ii. They will have the same amount of potential energy
$Ep = Eqd = 80000 \times 1.6 \times 10^{-19} \times 0.25 = 3.2 \times 10^{-15} J$

This means that the same amount of work will be done by the electric field on the proton and the electron. This means that they will have the same amount of kinetic energy by the time they reach the negative and positive plates respectively.

iii. The major difference is their mass, the proton is much more massive than the electron. They also have opposite signs, which means that the forces and velocities will be in the opposite direction.

iv. The final velocity of the electron is going to be much higher than the velocity of the proton because for the same amount of kinetic energy it has a higher velocity than the proton. This is because the mass of the electron is much smaller. If the kinetic energies are the same then the velocity will be higher.

They will also have velocities that are in the opposite direction.

2. DC Circuits

a. *i.* They are in series. This means we can just add their resistances together to get the total resistance.

ii. The correct equation is $R_T = R_1 + R_2 + \cdots$

So we just add the resistances together, each bulb has a resistance of 3Ω, so all together:

$R_T = 3 + 3 + 3 + 3 + 3 + 3 = 18\Omega$

b. *i.* This means that the voltage across them will be the same, split evenly between the six bulbs. The voltage across each of them will be 2V.

ii. Yes, because they are all in series. The current is going to be:

$I = \frac{V}{R} = \frac{12}{18} = 0.667A$

iii. $P = IV = 0.667 \times 2 = 1.33W$

iv. The voltage across each bulb is the same and so is the current going through them. This is because they have the same resistance. This means that they will use the same amount of power. The brightness of a bulb depends on the power that it uses, so they will have the same brightness.

c. *i.* A bulb blowing is the same as its resistance being practically infinite (or at least very high) because it is a break in the circuit.

ii. Because all of the bulbs are in series, the resistances add together. So if one of the bulbs is very high, the resistance of the whole circuit is very high. This means that no current flows any more.

iii. The current is still able to flow as the circuit is not broken, although the resistance will increase. The new circuit can have 3 bulbs blow (one from each branch).

d. *i.* Use the equation $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{3} + \frac{1}{3} = \frac{2}{3}$

Then we flip both sides to get $R_T = \frac{3}{2} = 1.5\Omega$

ii. Each branch of two bulbs has the same resistance and they are in series so we use :

$R_T = R_1 + R_2 + R_3 = \frac{3}{2} + \frac{3}{2} + \frac{3}{2} = \frac{9}{2}\Omega.$

$R_T = 4.5\Omega$

iii. Use Ohm's law. $I = \frac{V}{R} = \frac{12}{4.5} = 2.667A$

We can either calculate the voltage across a branch
$V = IR = 2.667 \times 1.5 = 4V$

Or because each branch has the same resistance, the voltage will split evenly. There are three branches so: $12 \div 3 = 4V.$

iv. Voltage stays the same in parallel, so the voltage across a single bulb in a branch will be 4V, and current splits, which means that the current through a branch is 1.33A. Therefore the power dissipated is $P = IV = 4 \times 1.5 = 6W$

v. Each bulb will be much brighter, as the power dissipated by a single bulb is 6W compared to 1.33W in the old configuration.

Variable Resistors

a. *i.* The power formula. $P = IV$

ii. $I = \frac{P}{V} = \frac{3}{6} = 0.5A$

b. *i.* When we decrease the resistance the current will increase because the voltage is staying the same. The current will also increase in the parallel branches.

ii. She could decrease the resistance of the variable resistor to increase the power used by the bulbs.

c. *i.* The voltage across the variable resistor must also be 6V, so that they both add to the 12V supplied by the source.

ii. The current across one branch is 0.5A. They have the same resistance so the current in the circuit is 1A.

iii. $R = \frac{V}{I} = \frac{6}{1} = 6\Omega.$

d. *i.* The resistance of the circuit will decrease, because more resistance has been added in parallel.

ii. The total current is going to increase, although the voltage across the bulbs will drop.

iii. The power dissipated is going to increase.

Series and Parallel Resistance

a. *i.* The resistance of a bulb is 6Ω, which means the total resistance is 18Ω since they are connected in series.

The current is 0.5A.

ii. $V = IR = 0.5 \times 18 = 9V$

b. *i.* The voltage across a single resistor is 3V, because they each have the same resistance, so $\frac{9}{3} = 3$.

ii. The current is 0.5A.

iii. $P = IV = 0.5 \times 3 = 1.5W$

c. *i.* 3 × 60 = 180 seconds

ii. $P = \frac{E}{t}$ which we rearrange for energy to get $E = Pt$

$E = 1.5 \times 180 = 270J$

d. *i.* Bulb A and B are in parallel, they each have a resistance of 6Ω.

$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{6} + \frac{1}{6} = 0.33\Omega.$

ii. They are in series, so we can just add this to the 6Ω resistor to get 6.33Ω.

iii. $I = \frac{V}{R} = \frac{9}{6.33} = 1.42A$

e. i. The current is 1.42A and the resistance of bulb C is 6Ω, so the voltage across it is $V = IR = 8.52\ V$. We can use the convenient equation for the power of something in terms of just the voltage and resistance.

$P = \frac{V^2}{R} = \frac{8.52^2}{6} = 12.1W$

ii. The current in one branch is going to be 0.72A because the bulbs have the same resistance and current splits in parallel. This is 1.42/2

The voltage across bulb A and bulb B is going to be 0.48V because the voltage across bulb C is $V = IR = 1.42 \times 6 = 8.52V$. The total voltage in the circuit must be 9, so the voltage across bulb B and C is 9–8.52=0.48V.

Which means the power is $P = IV = 0.7105 \times 0.474 = 0.33W$

iii. The power used by bulb A is much much less than bulb C, because the current through A and the voltage across A is much less than for bulb C. This means that bulb C is going to be a lot brighter.

iv. Bulb C is likely to blow, as the voltage across it is very high, and the current through it is large.

3. Electromagnetism

Induced Voltage and current

a. i. The voltage and resistance, using V = IR, both of which we have been given.

ii. Use Ohm's law $I = \frac{V}{R} = \frac{10}{25} = 0.4A$

b. i. Counterclockwise, from the negative terminal to the positive terminal.

ii. Electrons are moving down in the rod and the magnetic field is into the page, therefore the force experienced by the electrons is to the left.

iii. It is 15cm, as this is the part of the rod that is inside the circuit.

iv. $F = BIL$

$F = 2 \times 10^{-3} \times 0.4 \times 0.15 = 1.2 \times 10^{-4}N$ to the left.

c. i. Initially the rod moves to the left as the current in the wire cuts through the magnetic field and experiences force to the left.

ii. This acts as a break in the circuit, causing the current to stop flowing.

iii. This will mean that there are no longer any charges that are moving, which means that the force experienced by the charges in the rod will be zero and the rod will stop moving.

d. *i.* The charges in the rod are moving to the left and are cutting the magnetic field lines at a right angle. This means that they experience a force. This force is upwards for the electrons.

ii. This makes the top of the rod negatively charged and the bottom positively charged.

iii. This separation of charge induces a voltage in the rod and therefore in the circuit. This means that electrons flow clockwise, which means that the conventional current is counterclockwise.

A loop in a magnetic field

a. *i.* One side of the loop is 10cm

ii. $\mathrm{B} = 2\mathrm{T}$ $\quad$ $\mathrm{L} = 0.1\mathrm{m}$ $\quad$ $\mathrm{v} = 3.0\mathrm{ms}^{-1}$

iii. $V = BvL = 2 \times 3 \times 0.1 = 0.6V$

b. *i.* The electrons in BC are cutting the magnetic field, therefore they experience a force. Using the right hand slap rule electrons feel a force downwards, which means the electron flow is clockwise in the loop.

ii. Counterclockwise

iii. Using Ohm's law $I = \frac{V}{R} = \frac{0.6}{0.5} = 1.2A$

c. *i.* Again using the right hand slap rule, the electrons experience a force upwards, meaning that the electrons are flowing in a clockwise direction (the opposite direction as in BC).

ii. The induced voltage in AD is the same as in BC but in the opposite direction.

iii. Therefore two voltages are induced, in opposite directions, meaning the total induced voltage is 0.

d. *i.* The electrons are cutting the magnetic field, therefore they experience a force, which causes them to move down to D.

ii. The electrons move downwards. This is a separation of charge which is a voltage. This leads to the electrons moving around the circuit because it is a closed loop which induces a current.

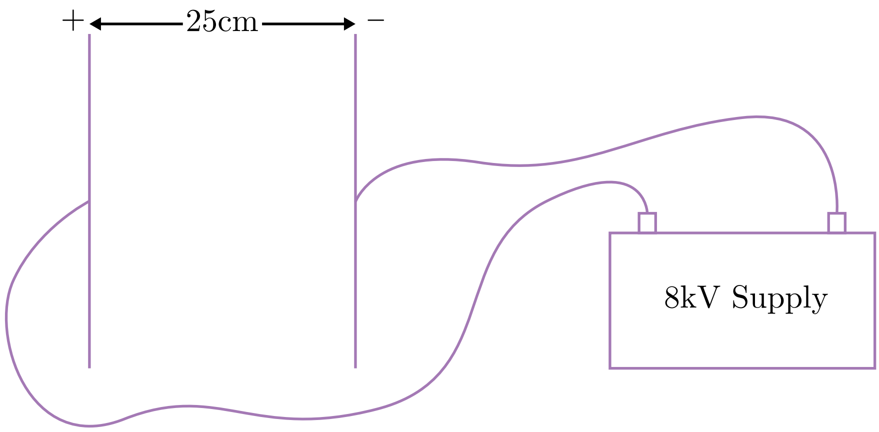
iii. The induced voltage is from A to D, which is a conventional current in the clockwise direction. The induced voltage is $V = BvL = 2 \times 6 \times 0.1 = 1.2V.$

iv. Everything else about the loop is the same, except for the speed, which has doubled. The induced voltage is proportional to the speed of the conductor, so the voltage will be double that of the loop entering at $3ms^{-1}$. The direction of the induced voltage is also in the opposite direction to that of the loop entering the magnetic field.

Section Three
Practice Exam

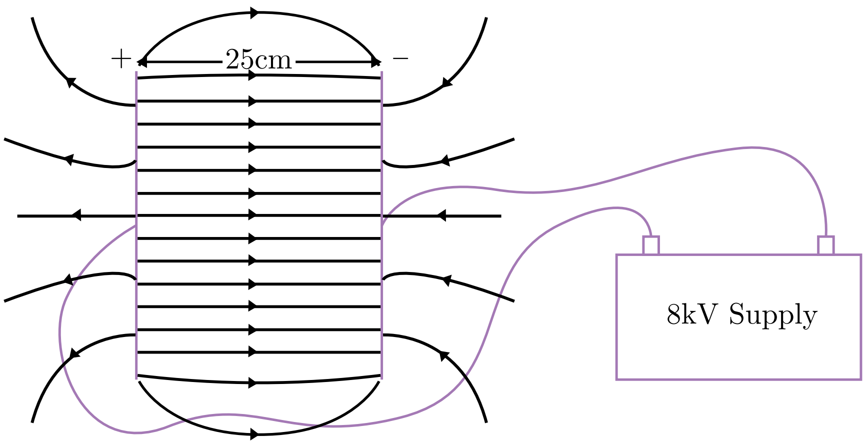
Question One – Electric Fields

Note: the diagram for this question has been corrected in newer versions of the workbook. The distance should be displayed as '25cm' to match the question. The updated diagram is provided below:



a. We use the equation $E = \frac{V}{d} = 32000 \text{Vm}^{-1}$

b.



c. The direction is to the right, from the positive plate towards the negative plate.

$F = Eq$

$F = 32000 \times 2.4 \times 10^{-11} = 7.68 \times 10^{-7} N$

d. $E_p = Eqd = 7.68 \times 10^{-7} 0.25 = 1.92 \times 10^{-7} J$

By conservation of energy $E_{p(lost)} = E_{k(gained)}$

$E_k = 1.92 \times 10^{-7} J = \frac{1}{2} m v^2$

$v = \sqrt{\frac{2 \times E_k}{m}} = \sqrt{\frac{2 \times 1.92 \times 10^{-7}}{0.01}} = 6.20 \times 10^{-3} ms^{-1}$ (3s.f.)

Answers

Answers

Question Two – Orbital Generators

a. $V = BvL$

$V = 25 \times 10^{-6} \times 3500 \times 25000 = 2187.5 = 2200V$

b. As the tether moves through the magnetic field of the Earth, the electrons inside it are travelling perpendicular to the field lines. This means that they experience a force due to the magnetic field.

The magnetic field is going into the page, so the electrons will experience a force in the upwards direction. This will cause electrons to accumulate at the top of the tether and therefore the top of the tether will be negatively charged.

c. When charges move at a right angle to the direction of a magnetic field the component of their velocity is entirely at a right angle to the magnetic field lines. The larger the component of the velocity of the tether that is at a right angle to the direction of the magnetic field lines, the larger the force that acts on the electrons in the tether.

This means that as the wire moves through the magnetic field, the tether has a smaller component of its velocity that is at a right angle to the magnetic field and therefore a smaller voltage will be induced in the tether.

d. As the shuttle moves with the tether through the Earth's magnetic field, work is being done on the charges inside the tether to induce a voltage. This means that the shuttle will lose kinetic energy as it moves through the magnetic field. The slower it moves, the smaller the voltage that is induced.

There is always an equal and opposite force acting on the tether opposing its travel through the magnetic field.

The only way to produce a constant voltage will be for the shuttle to gain some extra kinetic energy by burning fuel or providing some other thrust.

Question Three

a. $V = IR$

$R = \frac{V}{1} = \frac{4.5}{0.5} = 9\Omega$

b. The voltage across the 7Ω bulb is $V = IR = 0.5 \times 7 = 3.5V$.

The total voltage in the circuit is 4.5V and voltage stays the same in parallel, therefore the voltage across the 4Ω bulb is $4.5 - 3.5 = 1V$

c. The voltage across all of the bulbs in parallel is the same, 1V. The brightness of a bulb depends on the power it uses. The branch with a 4Ω bulb is going to have a larger current through it, $I = \frac{V}{R} = \frac{1}{4} = 0.25A$, which means it will use more power $P = IV = 0.25 \times 1 = 0.25W$. The branches with 8Ω bulbs on them will have a lower current running through them because they have a greater resistance, $I = \frac{V}{R} = \frac{1}{8} = 0.125A$, which means they will use less power $P = IV = 0.125 \times 1 = 0.125W$.

Therefore the 4Ω bulb will be brighter because it uses more power.

d. If the 4Ω bulb blows, the effective resistance of the circuit will increase. The remaining branch's resistance increases to 4Ω.

$\frac{1}{R_T} = \frac{1}{8} + \frac{1}{8} = \frac{1}{4}$

$R_T = 4\Omega$.

Therefore the effective resistance of the circuit increases to 11Ω.

$R_T = 4 + 7 = 11\Omega$.

The new current in the circuit will be 0.409A

$I = \frac{V}{R} = \frac{4.5}{11} = 0.409A\ (3s.f.)$

Because the current has dropped through the 7Ω, the voltage across the bulb will decrease $V = IR = 0.409 \times 7 = 2.864V$. Therefore the power used by the 7Ω bulb will decrease and so will its brightness.

Due to the increase in resistance of the branches with the 8Ω bulbs on them, the voltage across the branches will increase.

$V = IR = 0.409 \times 4 = 1.636V$ OR $V = 4.5 - 2.864 = 1.636V$

Therefore the current through the bulbs will also increase, as the voltage across them has increased $I = \frac{V}{R} = \frac{1.636}{8} = 0.205A$. Therefore the power used by the 8Ω bulbs increases $P = IV = 0.205 \times 1.636 = 0.335W$.

Brightness of a bulb depends on the power used by the bulb. The brightness of the two 8Ω bulbs will increase when the 4Ω bulb blows and the brightness of the 7Ω bulb will decrease.