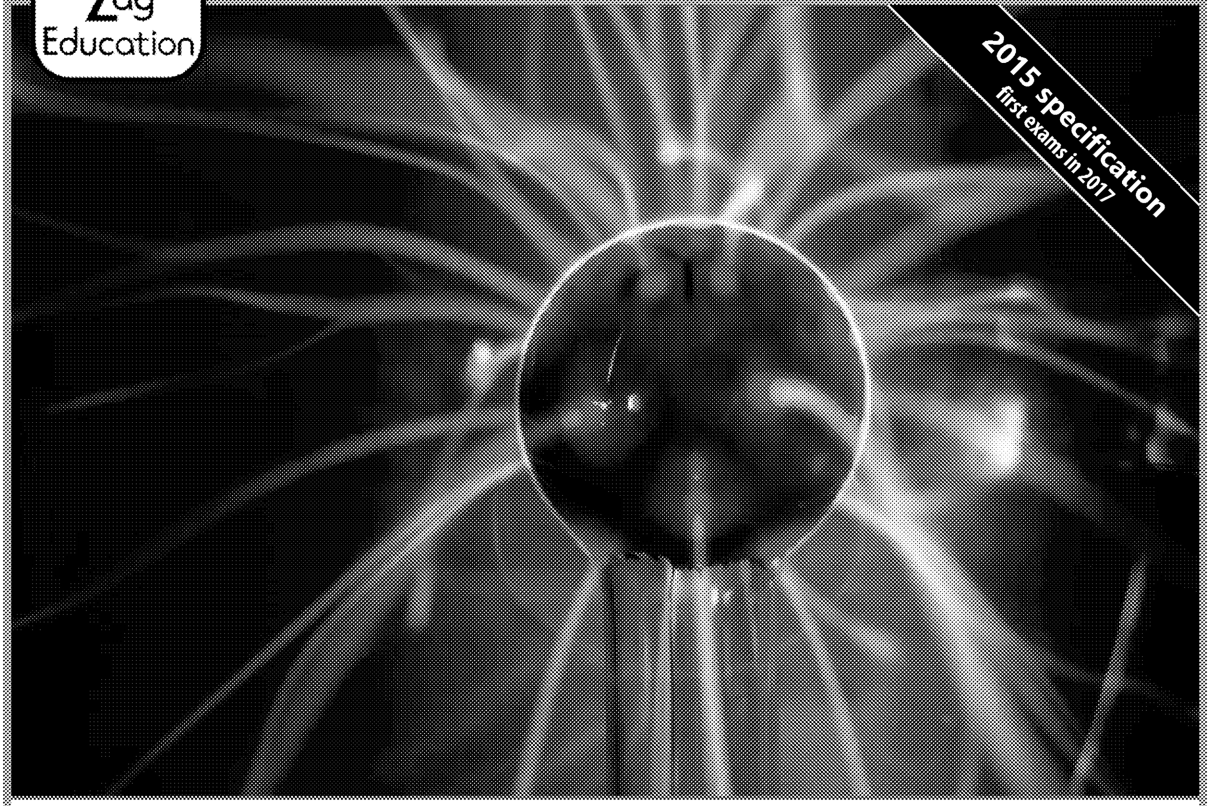
Zig Zag Education

Physics A Level | Edexcel | 9PH0



Electricity and Magnetism Technical Topics Worksheets

for A Level Edexcel Physics

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POD 8101

Contents

Teacher's Introduction

This activity pack is designed to help your student develop skills both during class and in an extracurricular setting. The content covers a range of topics across the A Level Edexcel course, specifically including content from **Topic 3: Electric Circuits**, and **Topic 7: Electric and Magnetic Fields**.

Remember!
Always check the exam board website for new information, including changes to the specification and sample assessment material.

Although each worksheet does cover a specific section of the A Level resource, the exercises are primarily skills-focused. These skills are all relevant to the A Level Edexcel examinations. The competencies which are developed and tested by this resource include:

- Understanding and analysing resistance changes with current, temperature and other factors for a variety of components
- Calculating resistance and resistivity of components, including components with changing dimensions
- Analysing circuits with multiple resistors in series and parallel
- Understanding and calculating how power is dissipated in components and circuits
- Analysing circuits with multiple power sources
- Analysing and design potential divider circuits
- Understanding how electric fields in dielectrics produces capacitance
- Analysing circuits with multiple capacitors
- Understanding how capacitors charge and discharge over time, including analysing graphs
- Analysing AC signals for information on circuits
- Calculating potential differences and currents in transformers, including cases where the transformers are not 100% efficient
- Calculating the e.m.f. induced in a coil rotating in a magnetic field

The resource opens with a student introduction followed by a refresher for GCSE Electricity topics. This is followed by 13 worksheets, each of which covers one or more skills outlined above.

Each worksheet contains a short section of background information, followed by worked examples and then in-depth questions to test students' knowledge (an answers section can be found at the end of the resource). The questions are split into three levels of increasing difficulty, illustrated using the headings *Bright spark*, *Charging up* and *Shocking!*.

The pack also includes three full exam-style questions, which closely replicate the style of question found in an examination paper.

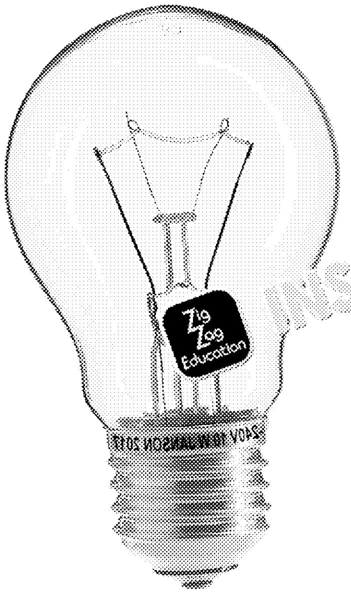
We hope this resource will be useful to your teaching, and help your students to tackle an area of physics which many find challenging, so that each student gains a deeper, holistic understanding of the subject.

SKILLS AND SPECIFICATION LINKS

This table is for either teachers' or students' use. It should help you to quickly see which topics are covered by this pack and which parts of the specification they relate to. As a result, you can identify areas which require improvement and use the appropriate worksheets.

Topic No.	Page Title	Page No.	Skills Covered	Specification Link
1	Resistors in series and parallel	13	• Performing calculations for combinations of resistors in series and parallel	3.36
2	Power	15	• Performing calculations involving power and energy usage in circuits	3.37
3	I–V characteristics	17	• Drawing and interpreting I–V graphs for a range of components	3.38
4	Resistivity	20	• Performing calculations using resistivity, including for non-regular objects	3.39
5	Potential dividers	23	• Interpreting and designing potential divider circuits using thermistors and LDRs • Performing calculations to find resistances and potential differences in potential divider circuits	3.43–3.44
6	Multiple power sources	26	• Analysing circuits with more than one power source • Performing calculations using circuits with more than one power source	3.45
7	Capacitance	29	• Understanding how capacitors use potentials to store charge • Perform calculations involving capacitance and dielectrics	7.116–7.117
8	Capacitors in series and parallel	32	• Perform calculations involving multiple capacitors in series and parallel	7.116–7.117
9	Charging and discharging capacitors	34	• Analysing capacitor charge and discharge graphs and using them in calculations	7.118/7.120
10	Transformers	38	• Performing calculations using transformers	7.125
11	Electromagnetic phenomena	41	• Analysing and interpreting situations involving Lenz's and Faraday's laws of electromagnetic induction	7.122/7.126
12	Electricity generation	44	• Performing calculations relating to electricity generation	7.124/7.127
13	Oscilloscopes	48	• Reading and setting up oscilloscopes • Performing calculations using alternating currents	7.129

STUDENT INTRODUC



The effects of electricity and magnetism have b
years, from lightning in the sky, static charge ca
objects, and fish such as the electric eel which c
it wasn't until the eighteenth century, with the wo
Franklin, that the connection between all of thes

In the nineteenth century, inventions such as Ales
scientists to generate electricity, while Michael F
Edison's filament bulb harnessed electricity for
from scientists such as Galileo Ferraris, Ányos Je
Westinghouse allowed electricity to be reliably
over large distances for use in industries, public

Today, the applications of electricity and magn
cables which transfer power across countries to
and hugely complex circuits which use, store and
display videos of cats on smartphones.

Electricity and magnetism come up in a few different sections of your A Lev
of different forms and applications. Electricity and magnetism topics includ
tricky to use, and require a strong understanding of the principles involved.
on electricity and magnetism, you'll have to be able to rearrange equations
recognise how the different equations can be used together.

This pack will help you develop several core skills related to electricity, mag

- understanding and analysing how resistance changes with current, temp variety of components
- calculating resistance and resistivity of components, including componen
- analysing circuits with multiple resistors in series and in parallel
- understanding and calculating how power is dissipated in components
- analysing circuits with multiple power sources
- analysing and designing potential divider circuits
- understanding how electric fields in dielectrics produces capacitance
- analysing circuits with multiple capacitors
- understanding how capacitors charge and discharge over time, includin
- analysing AC signals for information on circuits
- calculating potential differences and currents in transformers, including are not 100 % efficient
- calculating the e.m.f. induced in a coil rotating in a magnetic field

BACKGROUND – GCSE EL

If you studied GCSE Physics, you'll probably be familiar with some aspects o have seen *circuit* diagrams with the associated symbols, and designed and c You may have come across energy transfers, and calculated power dissipat and circuits. You'll probably have learnt about resistance and how resistors the current and potential difference in circuits. You may also have come ac magnetism are connected in the motor effect and generator effect, and how transformers and the national grid.

The next few pages are a quick summary of what you may have already co your memory and consolidate your knowledge before moving on to the mor you're not very confident, you should go slowly and spend some time buil knowledge and understanding before building on these topics with the A Le

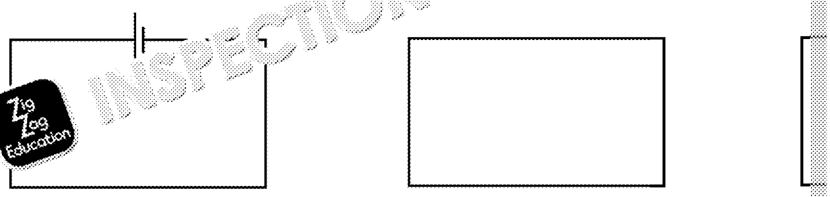
THE BASICS OF ELECTRICITY

Electricity is the **movement of charges** through a material, which transfers e

Materials which electricity can flow through are called **conductors.** Conduct metals or electrolytes.

- In a **metal** such as copper, negative electrons move round from negative
- In an **electrolyte** such as salt water, ions flow from one electrode to ano
- In **insulators** such as rubber, electrons are tightly bound to individual at cannot move around freely.

A **current** will only flow through a circuit if there is **a source of potential diff closed loop.**



Circuit A **Circuit B**

A current will only flow through Circuit A.
Circuit B is a closed loop, but there is **no power source**, so current will not
Circuit C has a power source but is **not a closed loop** – there is a gap in the

- **Current, *I*,** is the rate of flow of charge, **Q,** around a circuit.
- Current is measured in **amps**, given the symbol **A.**
- Charge is measured in **coulombs**, given the symbol **C.**

The charge transferred around a circuit is given by

$$Q = It$$

So if a current of 5 A flows for 10 seconds, $Q = 5 \times 10 = 50$ C of charge

Current is the same at all points of a loop of a circuit.

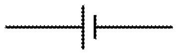
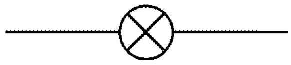
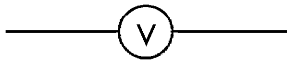
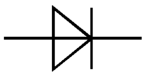
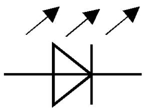
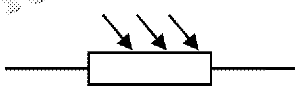
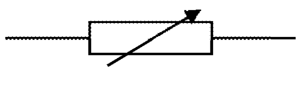
Potential difference or **voltage, *V*,** is the energy transferred to a charge ca Potential difference is the driving force behind the current in a circuit.

Potential difference is measured in **volts**, given the symbol **V.**

COMPONENTS

Each electrical component has a specific set of properties, and, therefore, car
specific effect.

Each component has its own symbol, so that circuit diagrams can be drawn s

Component	Symbol	
Cell		P
Bulb		
Voltmeter		M
Ammeter		
Ohmmeter		
Resistor		
Switch		C C
Diode		All
Light-emitting diode (LED)		Gi fl
Thermistor		
LDR (light-dependent resistor)		C
Variable resistor		Re

RESISTANCE

Resistance is the tendency of a component to oppose current.

Resistance, R, is measured in **ohms**, given the symbol Ω.

For a given potential difference, a component with **higher resistance** will h
through it.

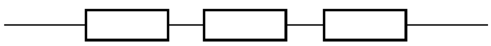
The relationship between current, potential difference and resistance is

$$V = IR$$

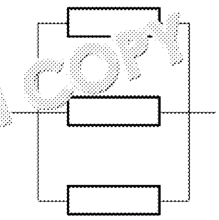
So a component with a resistance of 3 Ω and a current of 4 A flowing throu
will have a potential difference of $V = 3 \times 4 = 12$ V across it.

SERIES AND PARALLEL

Resistors and other components can be put into a number of different arran
are placed in **the same loop** of a circuit, they are **in series** with each other



When components are placed into **different loops** of the same circuit, they



When resistors are placed in series, the total resistance of the arrangement
The current through a series arrangement is the same at all points, and the
between the components.

For a series circuit, the total resistance is given by

$$R_{total} = R_1 + R_2 + R_3 + \ldots$$

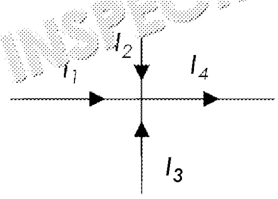
When resistors are placed in parallel, the total resistance of the arrangeme
the current has more paths to flow through, so each path needs to carry less
difference needed to power the same current. Potential difference is the sa
parallel circuit, while current is split across each branch.

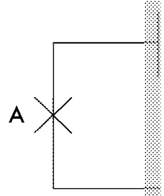
KIRCHHOFF'S LAWS

All circuits obey Kirchhoff's first and second laws. You may not have come across these laws by name, but you'll probably have used them before.

Kirchhoff's first law states that the current into any point of the circuit is equal to the current out of that point.

This means that charge is conserved throughout the circuit.

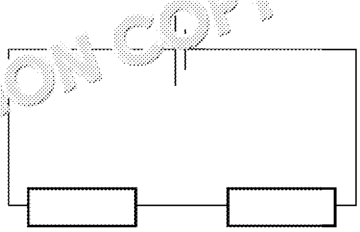




The current into a point must equal the current out of the point.
In the circuit on the left, $I_4 = I_1 + I_2 + I_3$.
In the circuit on the right, the current at point A = the current at point B.

Kirchhoff's second law states that the potential difference lost by charges i potential difference gained by the charges in the power source.

This means that energy is conserved throughout the circuit.



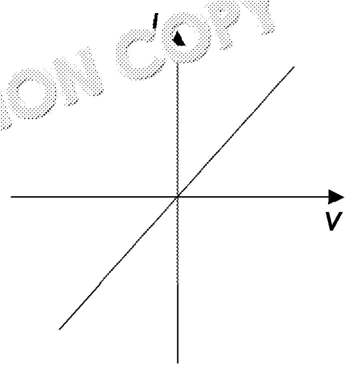
In this circuit, the potential difference supplied by the cell exactly equals th across both resistors.

Each resistor has a proportion of the potential difference across it – if the r the potential difference across each would be half the potential difference by the cell.

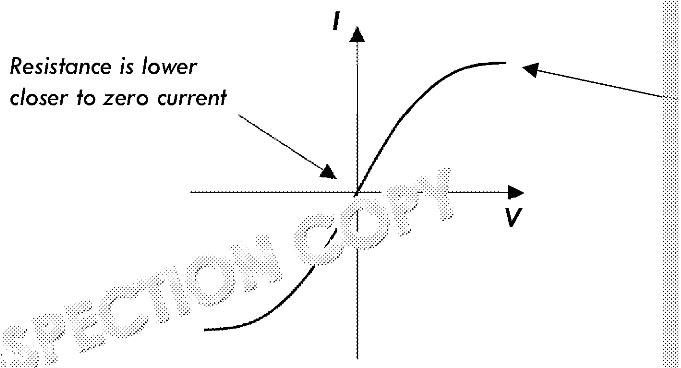
I-V CHARACTERISTICS

Components respond to increasing current and potential difference in differ

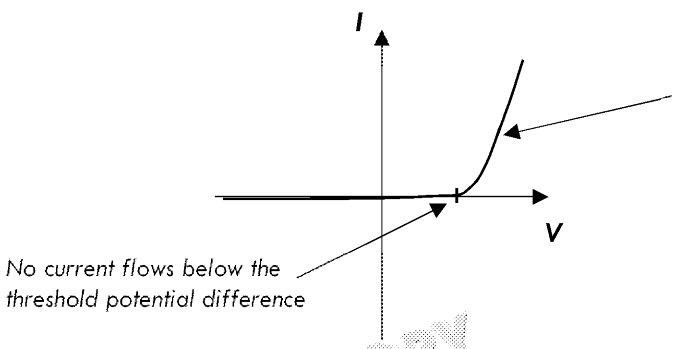
An **ohmic conductor** is one that has a **linear** relationship between potential d
resistance of an ohmic conductor is **constant**, no matter the current through it o



A **filament lamp** has increasing resistance with increased current. This is be
filament lamp increases as the current increases and a higher temperature in



A **diode** only allows current to flow through in a single direction above a thr



Thermistors and **Light-dependent resistors (LDRs)** are components that cha
their environment.

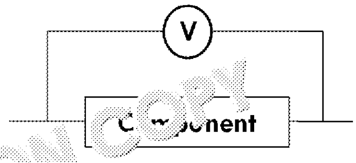
The resistance of a thermistor **decreases with increasing temperature.** This
measure temperature, or build a circuit that responds to changes in tempera

The resistance of an LDR **decreases with increasing light levels.** This mean
light intensity, or build a circuit that responds to changes in light levels, such
on automatically in the dark.

MEASURING CURRENT, POTENTIAL DIFFERENCE

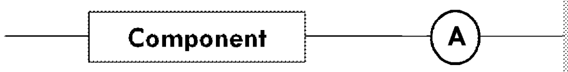
The potential difference across a component or section of a circuit can be me

A voltmeter should be placed **in parallel** with the component or circuit sectio



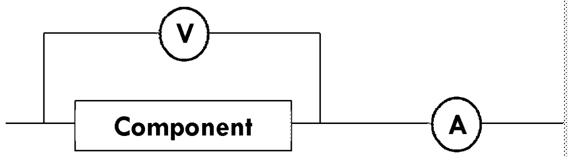
The current through a component can be measured using an **ammeter.**

An ammeter should be placed **in series** with the component being investiga



The resistance of a component can be measured with **both an ammeter and**

The ammeter is placed in series and the voltmeter in parallel with the compo equal to $R = \frac{V}{I}$.



A device called an **ohmmeter** can measure resistance directly. An ohmmete is a digital device that uses the same principles as using a voltmeter and ammeter. An ohmmeter is placed in parallel with the component.

Power

As a current passes through a component, energy is transferred. This transfe of energy can be into many different forms – for example, as light, heat, or kinetic energy.

The amount of power, P, transferred by a component is given by

$$P = IV = I^2R$$

Power is energy per second. The energy, E, transferred by a component in

$$E = Pt = QV$$

A component with a resistance of 8 Ω and a current of 2 A through it will transfer a power of $P = 2^2 \times 8 = 32$ W.

Over one minute, this component would have transferred $E = 32 \times 60 = 19$

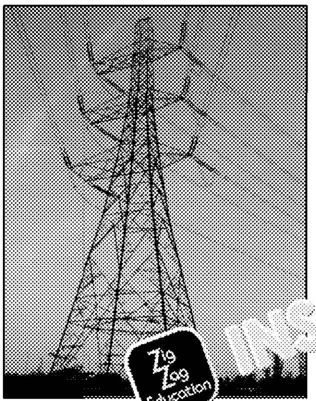
Not all power transfer in a component is useful. Some energy will be transfe considered waste energy. For example, a bulb will produce light but also p and sound. All components with a current running through them will produce

Efficiency is the ratio of energy that is transferred by a component or applic energy provided to the component or appliance.

$$efficiency = \frac{useful\ energy\ transferred}{total\ energy\ used} \times 100\ \%$$

A bulb that uses 50 W of electricity to produce 40 W of light would have a $\frac{40}{50} \times 100\ \% = 80\ \%$.

TRANSMITTING ELECTRICITY



All electrical circuits need a source of potential d
batteries are sufficient for small portable devices,
an external source of power.

Electrical energy production is one of the largest in
electricity is transmitted over the **National Grid.** Th
wires and transformers which transfer electricity fro
businesses.

Electricity is transmitted as an **alternating current**
direction of the current changes direction repeate

Alternating current is converted to **direct current** (
This means that the current supplied is a single, co

The electricity supplied to homes in the UK is AC, with a **potential difference of 2**

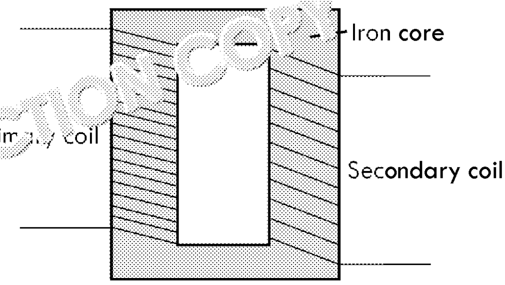
Transformers

When transmitting electricity, the current needs to be as low as possible to r
power, low current means high voltage (because $P = IV$ so $V = \frac{P}{I}$).

For this reason, electricity in power cables is transmitted at 400 kV, wherea
reaches homes at 230 V, or large businesses at 33 kV.

This change in potential differences is achieved through the use of **transform**

A transformer consists of two coils of wire linked by an iron core.



An alternating current in the primary coil induces an alternating current in th
the number of turns in the primary coil to the number of turns in the seconda
the potential difference across the primary coil to the potential difference a

The equation linking the number of turns in a transformer to the potential diff

$$\frac{N_s}{N_p} = \frac{V_s}{V_p}$$

N_p = nu
N_s = nu
V_p = po
V_s = po

THE GENERATOR EFFECT

When a conductor moves through a magnetic field, a current is produced in the conductor.

This is called the **generator effect** and is how most electricity is generated. In electrical generators, steam is heated up, creating high pressures and fast flows which are used to rapidly rotate a coil of wire in a magnetic field, generating a current in the coil.

The generator effect is also used in microphones, and other appliances where motion needs to be turned into a signal.

POP QUIZ

You can use this quiz to test how solid your knowledge of GCSE electricity is. content well, you'll have a much better shot at getting top marks in your A L

1. Fill in the gaps.

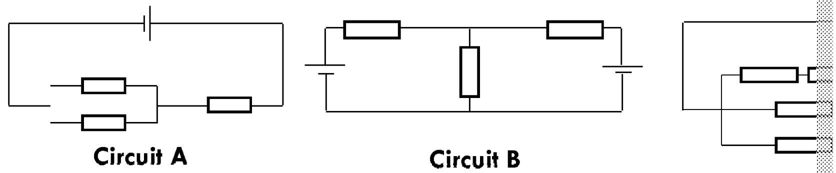
   Current is the rate of flow of ________ __ __.

   _______________ is the energy transferred to a charge.

   For a given potential difference, a lower-resistance component will have a through

2. 23 C of charge flows through a bulb over the course of one minute. Calculate the current flowing through the bulb.

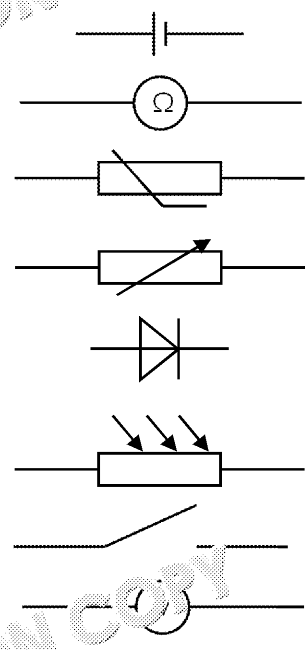
3. For each of the circuits below, state whether or not a current will flow, a



Circuit A **Circuit B**

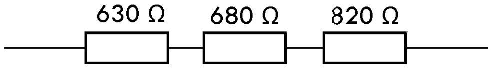
4. Match each component with its symbol and use.

Component	**Symbol**	
Thermistor		Pr
LDR (light-dependent resistor)		Cl
Voltmeter		M
Variable resistor		
Ohmmeter		
Cell		Re
Switch		Cl C
Diode		All



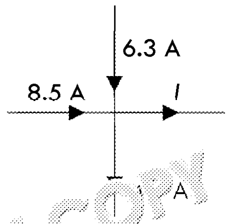
5. 850 mA flows through a resistor with a potential difference of 52 V acr Calculate the resistance of the resistor.

6. a) Calculate the total resistance of the resistors below.



   b) What would the effect be of putting the resistors in parallel? Expl

7. Calculate the value of *I* in the section of circuit seen below.



8. Fill in the gaps to describe Kirchhoff's laws.

Kirchhoff's first law states that the current into a junction equals ________

Kirchhoff's second law states that the potential difference provided by a p

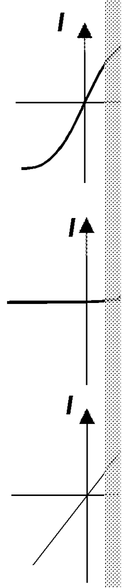
________________________.

9. Match the components with their *I*–*V* graphs.

Ohmic conductor

Filament lamp

Diode



10. Draw a circuit which could be used to measure the resistance of a comp

11. a) A 220 Ω resistor has 190 mA flowing through it.
    Calculate the power transferred to the component.

    b) 370 J of energy is transferred to 8.3 C.
    Calculate the potential difference which transfers the energy.

12. Describe how and why transformers are used in the National Grid.

13. State a use of the generator effect.

1. RESISTORS IN SERIES AND I

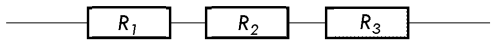
TOPIC 3: ELECTRIC CIRCUITS

BACKGROUND

Current and potential difference act very differently in series and in parall

	Current	Potenti
In series…	Current is the same at all points	Potential difference is sp
In parallel	Current is split across each 'branch' of the circuit	Potential difference is th of the circuit

The total resistance of components in series is



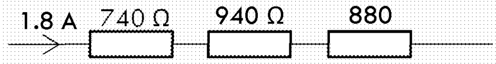
$$R_{total} = R_1 + R_2 + R_3 + \ldots$$

The total resistance of c parallel is

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$$

Example 1

Calculate the potential difference across the section of circuit below.



The current is the same at each p we can treat all three resistors a

These components are in **series,** s

$R_{total} = R_1 + R_2 + R_3$

Substituting in values gives

$R_{total} = 740 + 940 + 880$

$R_{total} = 2560\ \Omega$

Use $V = IR$
and substitute in values to give

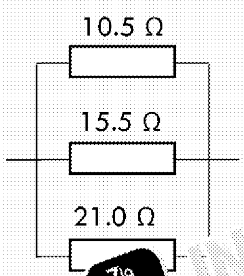
$V = 1.8 \times 2560$

$\boldsymbol{V = 4.6\ k\Omega}$

Another method would be to indi difference across each resistor a

Example 2

Calculate the total resistance of the section of circuit below.



These components are in **parallel,** so we need to

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

We first need to rearrange for R_{total}

$$R_{total} = \frac{1}{1/_{R_1} + 1/_{R_2} + 1/_{R_3}}$$

then substitute in values

$$R_{total} = \frac{1}{1/_{10.5} + 1/_{15.5} + 1/_{21.0}}$$

$\boldsymbol{R_{total} = 4.82\ \Omega}$

***Note**: for components in parallel, the total resista resistance of any one component!*

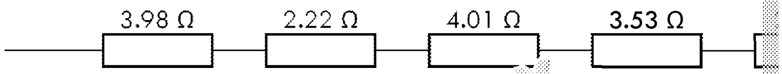
You might find it easier to first find

$1/_{R_1} + 1/_{R_2} + 1/_{R_3}$ *(in this case 0.2074) and th*

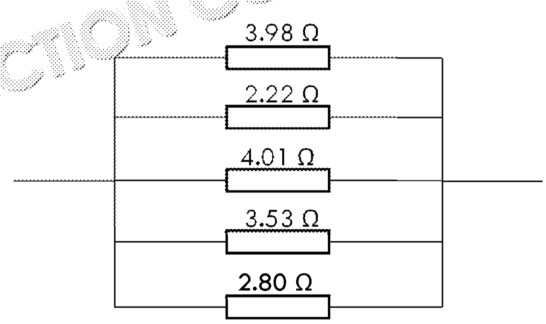
QUESTIONS

Bright spark

1. Calculate the combined resistance of the components below.

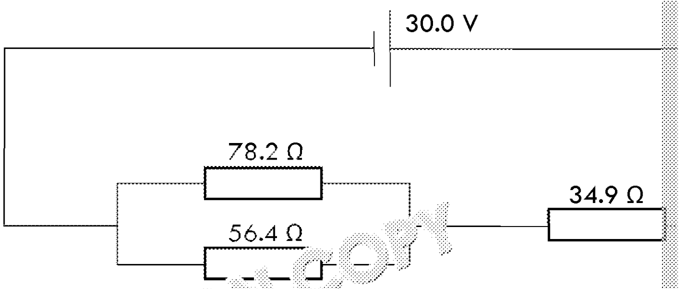


2. Calculate the combined resistance of the components below.

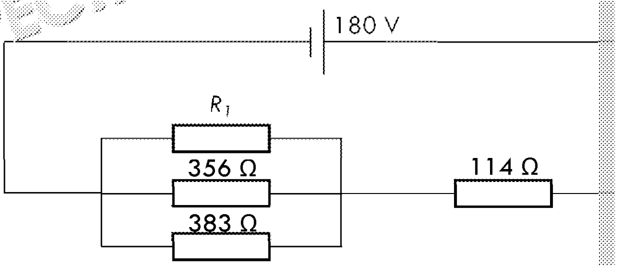


Charging up

3. Calculate the value of I in the circuit below.

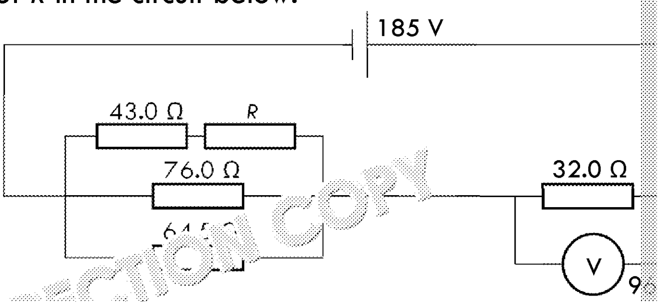


4. Calculate the value of R_1 in the circuit below.



Shocking!

5. Calculate the value of R in the circuit below.



6. A circuit is set up with a power source, an ammeter, a 12 Ω resistor and
The ammeter records a reading of 5 A.

The resistor, R_1, *is replaced with another resistor,* R_2, and the reading on t

A new set up was then arranged with a new power source, which suppli
26 V, an ammeter, and the two resistors, R_1 *and* R_2, in series. The amme

Calculate R_1 *and* R_2.

2. POWER

TOPIC 3: ELECTRIC CIRCUITS

BACKGROUND

A potential difference across a wire causes a transfer of energy. This can either be useful energy, such as causing a motor to turn or wasted energy, such as a wire heating when a current flows through.

The power transferred in a component is given by:

$$P = IV$$

which can be written as:

$$P = I^2R$$

or:

$$P = \frac{V^2}{R}$$

Example 1
There is a potential difference of 15 V across a 40 Ω resistor.

Calculate the energy transferred across the resistor over one hour.

We have $V = 15$ V and $R = 40\ \Omega$.

The equation $P = \frac{V^2}{R}$ will give the power transferred … want the total energy.

Power is defined as the energy transferred per unit …

so

$$W = Pt = \frac{V^2}{R}t$$

In this case, $t = 1$ hour $= 60 \times 60 = 3600$ s

Substituting in values gives

$$W = \frac{15^2}{40} \times 3600$$

$$\mathbf{W = 20250\ J}$$

Example 2
A kettle has a power rating of 80 W. The element of the kettle has a resistance of 600 Ω. Calculate the charge transferred to the element over two minutes.

We have $P = 80$ W and $R = 600\ \Omega$ and want charge …

Current is defined as the charge through a component … $Q = It$.

In this example, t = two minutes $= 2 \times 60 = 120$ s.

To find current, we can use

$$P = I^2R$$

which rearranges to

$$I = \sqrt{\frac{P}{R}} \quad \text{so} \quad Q = \sqrt{\frac{P}{R}}\,t$$

Substituting in values gives

$$Q = \sqrt{\frac{80}{600}} \times 120$$

$$\mathbf{Q = 43.8\ C}$$

Example 3

A power station produces 2.0 MW of power and transmits a potential difference 275 kV through wires with a resistance of 650 Ω.

Calculate the power dissipated by the cables.

There are two powers in this situation – the po… power station, P, and the power dissipated b… It's important not to get these two mixed up.

The power dissipated by the cables is given b…

$P_{dissipated} = I^2R$

Substituting $I = \frac{P}{V}$ g ve…

$\frac{P^2R}{V^2}$

Substituting in values gives

$$I^2R = \frac{P^2R}{V^2}$$

$$I^2R = \frac{\left(2.0\times10^6\right)^2\times650}{\left(275\times10^3\right)^2}$$

$\boldsymbol{I^2R = 34\ \mathrm{kW}}$

QUESTIONS

Bright spark

1. A bulb gives out a power of 40 W. It is connected to mains electricity, difference of 230 V.

   Calculate the resistance of the filament in the …

2. A resistor has a resistance … and a current of 77.1 mA runnin… Calculate the ener… …ed by the resistor.

Charging

3. A cran… powered by a cable which has a resistance of 855 Ω and a… across it.

   Over five minutes, the crane lifts a 3150 kg crate by 9.39 m.

   Calculate the efficiency of the crane.

4. 146 J of energy is transferred to a heating element over one minute. … resistance of 95.4 kΩ.

   Calculate the charge that passes through the heating element.

Shocking!

5. While being used, the cables that power magne… a particle accele… MW of power, and have a potential diff…ce … 30.9 MV across the…

   The cables have a resistance … 0 …Ω.

   Calculate the eff… …e cables which supply the magnets used i…

6. A ma… propulsion system consists of a track which accelerates 10… 68.6 m… in 5.36 s.

   The tracks dissipate a power of 721 kW, and have a resistance of 90… of 25.6 kV across them.

   Calculate the efficiency of the magnetic propulsion system.

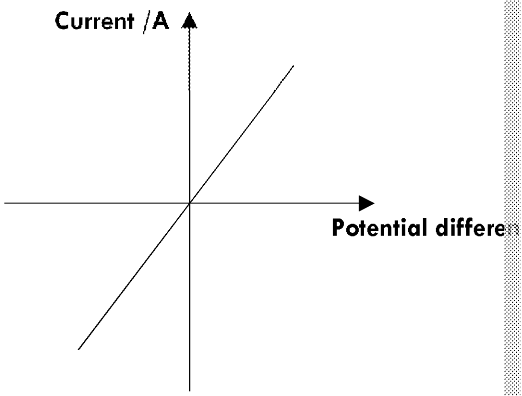
3. I–V CHARACTERIS

TOPIC 3: ELECTRIC CIRCUITS

BACKGROUND

Different components respond to high and low ... differently, which can be shown on an *I–V* graph.

The *I–V* graph of an ohmic ... is seen below.

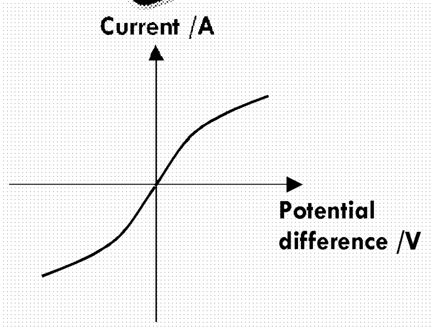


Resistance is given by $R = \frac{V}{I}$, and for an I–V graph gradient $= \frac{I}{V}$, so $R = \frac{}{}$

You may encounter *I–V* graphs with potential ... on the y-axis and ... is called a *V–I* diagram. For a *V–I* graph ... gradient.

Example 1

The I–V g... f ... lament lamp is shown bel...



Describe the resistance of a filament lamp at different currents.

EXTENSION:
Explain the properties of a fil... lamp in terms of charg...

For an I–V graph, gradient $= \frac{I}{V} =$ ...
gradient means a lower resistance, ...
gradient means a higher resistance.

The gradient is shallower at more p... and potentials than near zero, so th... lamp increases with current and pot...

EXTENSION:
At higher currents, more power is di... heats up.

As the filament heats up, atoms vibr... of electrons and increasing resistanc...

EXAM
Remem...
out whi...

Example 2

Current only passes through a semiconductor diode above a positive potential difference threshold, V_0.

Above this threshold, the resistance of the diode decreases with increased current.

Current will flow at high negative potential differences.

Draw the V–I graph you would expect for a semiconductor diode.

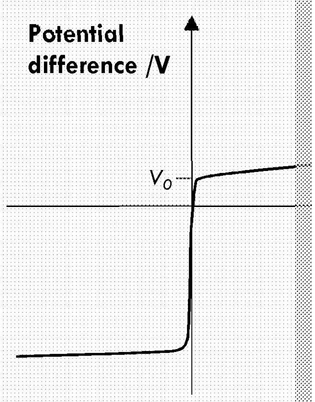
A V–I graph has potential difference, V, and current, I, on the x-axis.

A current will only flow above V_0, *so below this value on the y-axis,* $I =$

Above V_0 the resistance decreases. $R = \frac{V}{I}$ so R = gradient, so the gradient will decre

At high negative potential differences, c

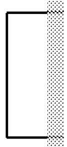
This means that the V–I graph for a sem



QUESTIONS

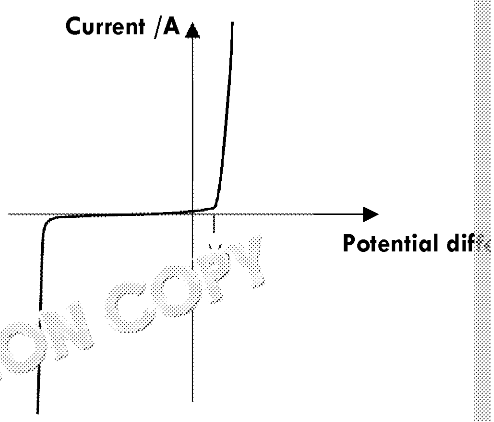
Bright spark

1. The circuit to the right is used to measure the resistance of a metal resistor with different potential differences across the resistor.

   As the current through the resistor increases, it heats up. Sketch the I–V graph you would expect for the resistor.

2. Explain the features of the graph seen below.



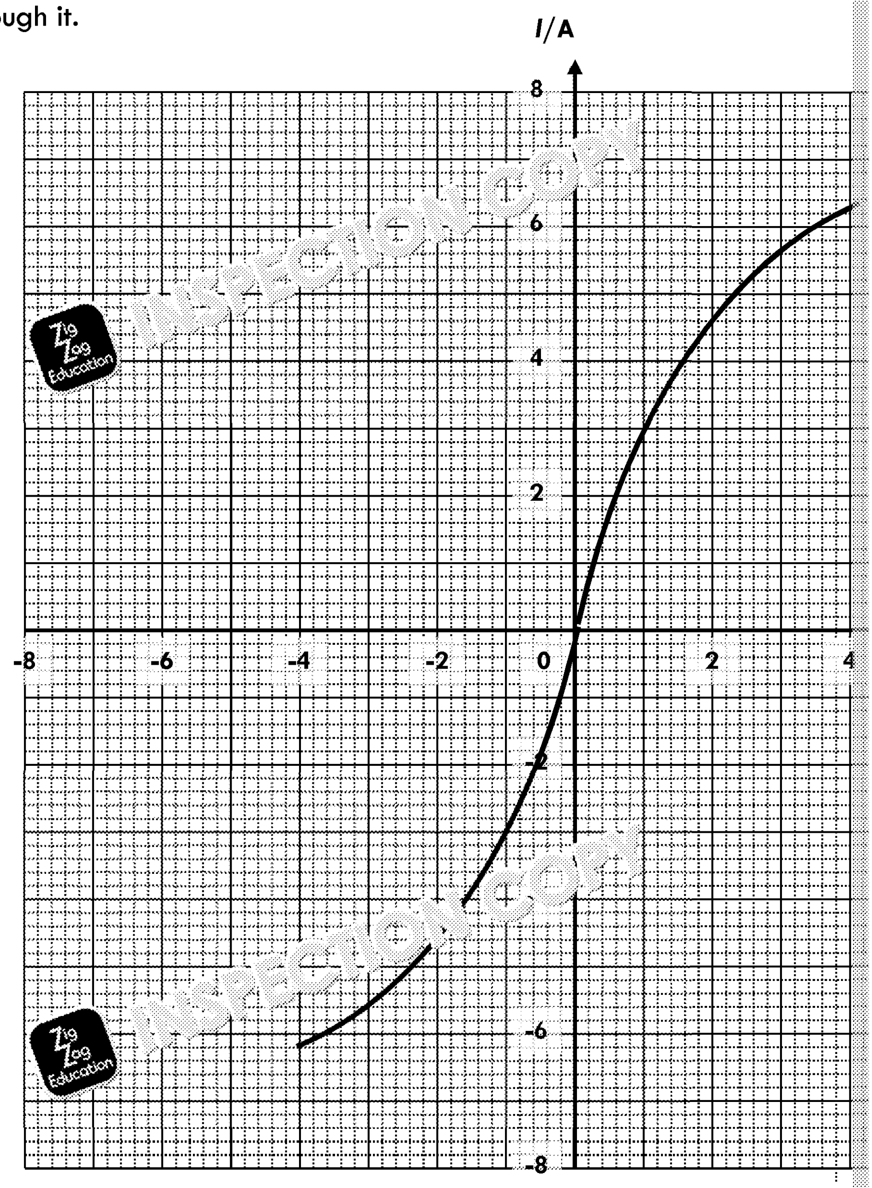
Charging u

3. The current through and potential across a negative temperature coeffi measured at a number of currents and temperatures.

   Sketch the I–V graphs you would expect for the thermistor at different features of the graph.

4. Describe an experiment you could perform to investigate the I–V charc

5. Calculate the resistance when the component shown by the graph belo through it.



Shocking!

6. A component consists of a negative region with an excess of electrons c lack of electrons.

   Electrons can flow easily from the negative region to the positive regio as the electrons are attracted to the positive region.

   As the current increases, more electrons are liberated from atoms in the resistance.

   Predict the shape of the I–V graph of this component.

7. A memristor is a component which can record its previous resistance, an accordingly.

   At high currents, the memristor always has the same resistance. At low c on two different resistances, depending on the previously 'remembered

   A memristor switches between high and low resistances at high currents, memristor is smooth at high currents.

   If a memristor is currently at its higher resistance, it will remain at its hig high currents.

   Sketch an I–V graph for a memristor.

4. RESISTIVITY

TOPIC 3: ELECTRIC CIRCUITS

BACKGROUND

The resistance of an object – how well it can stop conduct a current – depends on a couple of different factors.

- **Material:** A conductor, such as metal, will have a lower resistance than an insulator, such as wood or rubber, because it's easier for a current to pass through.
- **Dimen**sions: A longer wire will have a higher resistance because there current. A narrower wire will have a higher resistance as well because current to pass through.

The resistance of an object is given by the following equation:

$$R = \frac{\rho L}{A}$$

or by rearranging it as follows:

$$\rho = \frac{RA}{L}$$

Example 1

Copper is used in electrical wires. 1.55 km of copper has a resistance of 20.7 mΩ.

The cross-section of the copper wire is a circle with a radius of 2.00 cm.

Calculate the resistivity of the copper wire.

EXTENSION:

An additional 380 m of wire is added to the copper wire.

Calculate the new resistance of the wire.

We have $R = 20.7 \times 10^{-3}\ \Omega$, $L_1 = 1.55$ k
$r_1 = 2.00$ cm $= 2.00 \times 10^{-2}$ m.

First, we need the cross-sectional area of t

$A = \pi r^2$

$A = \pi \times (2.00 \times 10^{-2})^2$

$A = 1.257 \times 10^{-3}$ m²

Now we can calculate the resistivity of the

$$\rho = \frac{RA}{L}$$

$$\rho = \frac{20.7\times10^{-3} \times 1.257\times10^{-3}}{1.55\times10^{3}}$$

$\boldsymbol{\rho = 1.68 \times 10^{-8}\ \Omega\ \mathrm{m}}$

EXTENSION:

The resistivity of the copper is constant an hasn't changed.

The new length of the copper wire is 155

$$R = \frac{\rho L}{A}$$

$$R = \frac{1.68\times10^{-8} \times 1930}{1.257\times10^{-3}}$$

$\boldsymbol{R = 25.7\ \mathrm{m}\Omega}$

EXA
Reme
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In thi
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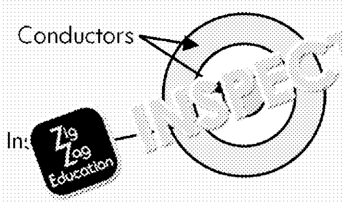
Example 2
A cable consists of a central wire, with a conductive ring around the central wire. An insulating ring lies between the wire and outer conductive ring.

The cross-section of the cable is seen here.



- In the cable, the inner wire is made of copper, with a resistivity of 1.68×10^{-8} Ω m. The cross-sectional area of the inner wire is 2.80×10^{-5} m^2.
- The outer ring is made of iron, which has a resistivity of 9.71×10^{-8} Ω m. The cross-sectional area of the outer ring is 1.60×10^{-4} m^2.
- A potential difference is applied across the cable.

Calculate the total resistance of 1.00 m of the cable.

The resistance of an object i

$$R = \frac{\rho L}{A}$$

So the resistance of the inne

$$R_{inner} = \frac{1.68\times10^{-8}\times1.00}{2.80\times10^{-5}}$$

$$R_{inner} = 6.000\times10^{-4}\ \Omega$$

And the resistance of the ou

$$R_{outer} = \frac{9.71\times10^{-8}\times1.00}{1.60\times10^{-4}}$$

$$R_{outer} = 6.069 \times 10^{-4}\ \Omega$$

The wire and ring are in pa resistance is given by

$$\frac{1}{R_{total}} = \frac{1}{R_{inner}} + \frac{1}{R_{outer}}$$

$$R_{total} = \frac{1}{{}^{1}/_{R_{inner}} + {}^{1}/_{R_{outer}}}$$

$$R_{total} = \frac{1}{{}^{1}/\left(6.000\times10^{-4}\right) +}$$

$$\mathbf{R_{total} = 3.02 \times 10^{-4}\ \Omega}$$

QUESTIONS

Bright spark

1. An iron bar has a length of 37.1 cm, and its cross-section is a square wi

   The resistivity of iron is $9.71 \times 10^{-8}\ \Omega$ m.

   Calculate the resistance of the iron bar.

2. A wire has a resistivity of $6.72 \times 10^{-7}\ \Omega$ m, and a resistance of 92.3 m

   The cross-sectional area of the wire is 7.07 mm^2.

   Calculate the length of the wire.

Charging up

3. A 3.00 cm diameter wire is cut from 2.40 m to 1.90 m.

   The resistance of the wire decreases by 83.4 Ω.

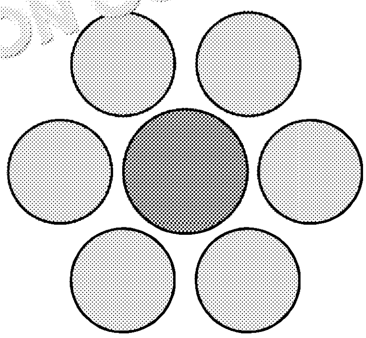
   Calculate the resistivity of the wire.

4. The resistivity of lead is $2.20 \times 10^{-7}\ \Omega$ m. A lead pipe has an inner ra radius of 8.30 cm for a length of 1.60 m. The pipe then widens so that cm and an outer radius of 9.31 cm for 23.0 cm.

   Calculate the resistance of the lead pipe.

Shocking!

5. A cable consists of a carbon wire, with a resistivity of $4.56 \times 10^{-6}\ \Omega\ m$, wires, with a resistivity of $2.82 \times 10^{-8}\ \Omega$ m.



   The radius of the carbon wire is 8.50 mm. The radius of each aluminium

   Calculate the power dissipated by 200 m of the cable carrying 320 mA

6. A lump of conductive putty is moulded into a cylinder. The length of the the radius is 0.662 cm.

   The resistance of the putty cylinder is 31.8 Ω.

   The same volume of putty is remoulded into a cylinder with a length of

   Calculate the resistance of the new cylinder.

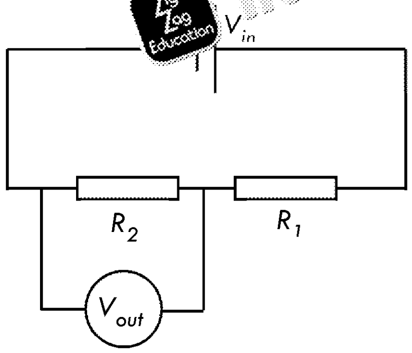
5. POTENTIAL DIVID

TOPIC 3: ELECTRIC CIRCUITS

BACKGROUND

A potential divider is used to create an output potential difference that is a specific fraction of the input potential difference.

The layout of a simple potential divider can be seen below.



The equation for the output voltage of a potential divider is

$$V_{out} = V_{in}\frac{R_2}{R_1 + R_2}$$

or

$$\frac{V_{out}}{V_{in}} = \frac{R_2}{R_{total}}$$

The derivation

This can be derived by considering the current through the entire circuit.

$V_{in} = IR_{total} = I(R_1 + R_2)$

$I = \frac{V_{in}}{R_1 + R_2}$

$V = IR$ so

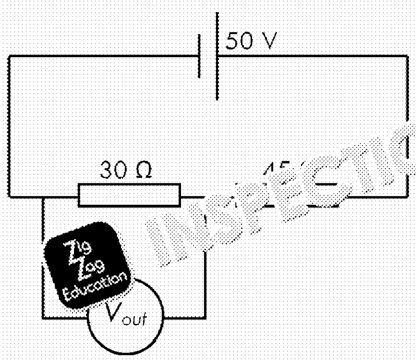
$V_{out} = V_{in}\frac{R_2}{R_1 + R_2}$

You should understand how to derive these equations.

Example 1

A circuit is shown below.

Calculate the value of V_{out}.



We need to use

$V_{out} = V_{in}\frac{R_2}{R_1 + R_2}$

With V_{in} = 50 V, R_2 = 30 Ω

We want V_{out}, so there's no n

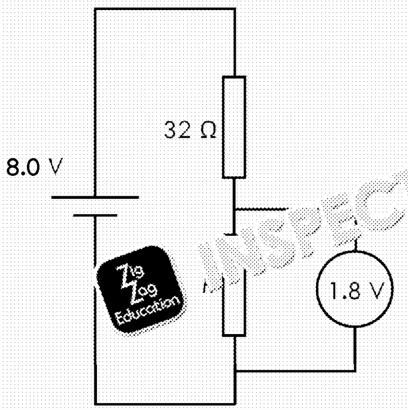
equation.

Putting the numbers in gives

$V_{out} = 50 \times \frac{30}{30 + 45}$

$\mathbf{V_{out} = 20\ V}$

Example 2
A circuit is shown below.
Calculate the value of R.



We need to use

$$V_{out} = V_{in}\frac{R_2}{R_1 + R_2}$$

With V_{out} = 1.8 V, V_{in} = 8.0 V anc

We want R = ... so we'll need to r

$V_{out}(R_1 + R_2) = V_{in}R_2$ [mu

$V_{in}R_2 - V_{out}R_2 = V_{out}R_1$ [mu V_{ou}

$R_2(V_{in} - V_{out}) = V_{out}R_1$ [take

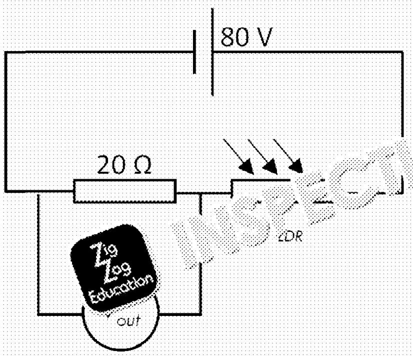
$R_2 = \frac{V_{out}R_1}{V_{in} - V_{out}}$ [divi

and substitute values in

$$R = \frac{1.8 \times 32}{8.0 - 1.8}$$

$\boldsymbol{R = 9.3\ \Omega}$

Example 3
A light-sensing circuit is seen below.



At $I = 30$ W m^{-2}, V_{out} is 40 V.

Calculate R_{LDR} at $I = 90$ W m^{-2}.

For this circuit, $R_{LDR} \propto I$

We first need to find R_{LDR} at 30 W

$$V_{out} = V_{in}\frac{R_2}{R_1 + R_2}$$

Rearrange f...

$V_{out}(R_1 + R_2) = V_{in}R_2$ [multi

$V_{out}R_1 = V_{in}R_2 - V_{out}R_2$ [multi from b

$R_1 = \frac{V_{in}R_2 - V_{out}R_2}{V_{out}}$ [divid

and substitute values in

$$R_{LDR} = \frac{80 \times 20 - 40 \times 20}{40}$$

$R_{LDR} = 20\ \Omega$

We know that $R_{LDR} \propto I$

so

$$\frac{R_{LDR\ 30}}{R_{LDR\ 90}} = \frac{I_{30}}{I_{90}}$$

Rearrange for $R_{LDR\ 90}$

$R_{LDR\ 90} = \frac{I_{90}}{I_{30}} R_{LDR\ 30}$ [multi both si

Substitute values in

$$R_{LDR\ 90} = \frac{90}{30} \times 20$$

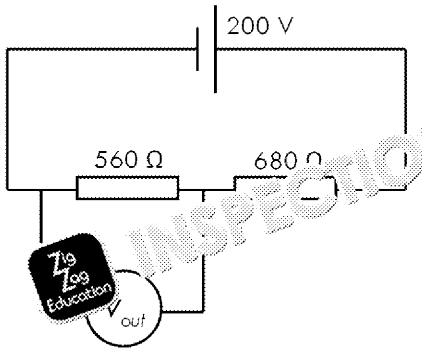
$\boldsymbol{R_{LDR\ 90} = 60\ \Omega}$

EXAM TIP
This question has a lot of variable
Variables at a light intensity of x V
So the resistance of the LDR at 30

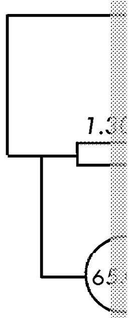
QUESTIONS

Bright spark

1. Calculate the value of V_{out} in the circuit below.

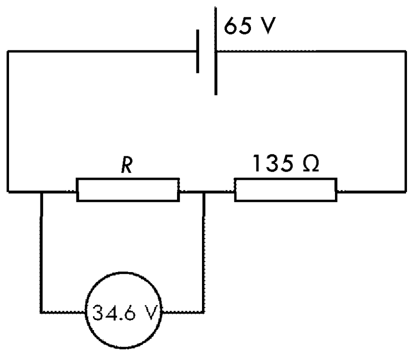


2. Calculate V_{in} i

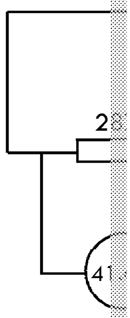


Charging up

3. Calculate the value of R in the circuit below.



4. Calculate R in

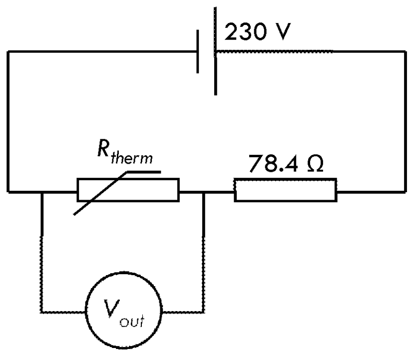


Shocking!

5. At 200 K, R_{ther} [illegible] Ω.

   The res[illegible] of the thermistor is $R_{therm} \propto \frac{1}{T}$.

   Calculate the temperature at which $V_{out} = 170$ V.

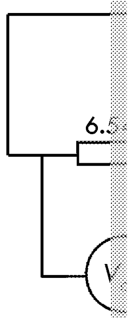


6. At 30.0 W m

   The response o

   Calculate the li

   V_{out}= 54.1 V.



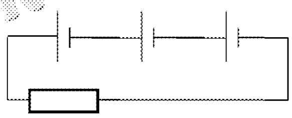
6. MULTIPLE POWER S(

TOPIC 7: ELECTRIC AND MAGNETIC FIELDS

BACKGROUND

Power sources can be placed in series or in parallel.

Series

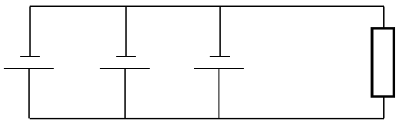


For a series circuit, the e.m.f. delivered to the circuit is the sum of the e.m.f.s (

$$\varepsilon_{total} = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \ldots$$

For power sources in series, the current can actually decrease – adding cells also adds internal resistance, so the total resistance of the circuit increases.

Parallel



Only cells providing the same e.m.f. can be put into parallel, and the e.m.f. (equal to the e.m.f. of a single cell.

$$\varepsilon_{total} = \varepsilon_1 = \varepsilon_2 = \varepsilon_3 = \ldots$$

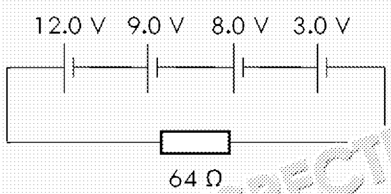
When putting power sources in parallel, the current tends to increase compa(putting the cells in parallel decreases the combined internal resistance, so th(decreases.

Internal resistance
For a cell with a non-negligible internal resistance, the e.m.f. of the cell is gi(

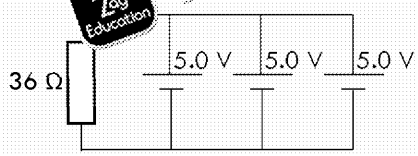
$$\varepsilon = I(R - r)$$

Example 1
Calculate the currents through the resistors in the circuits below.

Circuit 1



Circuit 2



Circuit 1
For a series circuit

$\varepsilon_{total} = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \varepsilon_4$

Substituting in values gives

$\varepsilon_{total} = 12.0 + 9.0 + 8.0 + 3.0$

$\varepsilon_{total} = 32\ V$

which means there's a potential difference of 32 V across the resistor.

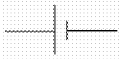
$V = IR \rightarrow I = \frac{V}{R}$

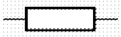
Substituting gives

$I = \frac{32}{64}$

$\boldsymbol{I = 0.50\ A}$

Example 2
In an experiment, the following components must be used:

8 ×  $\varepsilon = 28$ V, $r = 0.80\ \Omega$

1 ×  $R = 140\ \Omega$

Determine whether the cells should be placed in series or parallel to reduce the dissipation of energy in the circuit.

The power dissipated by a resistor is given

For cells in series

$\varepsilon_{series} = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \ldots$

so

$\varepsilon_{series} = 8 \times 28$

$\varepsilon_{series} = 224$ V

For cells in parallel

$\varepsilon_{parallel} = \varepsilon_1 = \varepsilon_2 = \varepsilon_3 = \ldots$

$\varepsilon_{parallel} = 28$ V

for a cell with non negligible internal resist

$\varepsilon = I\ (R - r)$

which rearranges to

$$I = \frac{\varepsilon}{R - r}$$

However, we can't use $r = 0.80\ \Omega$ as this is
have to use the effective internal resistance

For cells in series

$r_{series} = r_1 + r_2 + r_3 + \ldots$

$r_{series} = 8 \times 0.80$

$r_{series} = 6.4\ \Omega$

$$I_{series} = \frac{\varepsilon_{series}}{R - r_{series}}$$

$$I_{series} = \frac{224}{140 - 6.4}$$

$I_{series} = 1.68$ A

For cells in parallel

$$\frac{1}{r_{parallel}} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \ldots$$

For n power sources in parallel

$$\frac{1}{r_{parallel}} = \frac{n}{r}$$

$$r_{parallel} = \frac{r}{n}$$

$$r_{parallel} = \frac{0.80}{8}$$

$r_{parallel} = 0.10\ \Omega$

$$I_{parallel} = \frac{\varepsilon_{parallel}}{R - r_{parallel}}$$

$$I_{parallel} = \frac{28}{140 - 0.10}$$

$I_{parallel} = 0.20$ A

The parallel arrangement draws less curr arrangement, so this dissipates less pow placed in parallel.

QUESTIONS

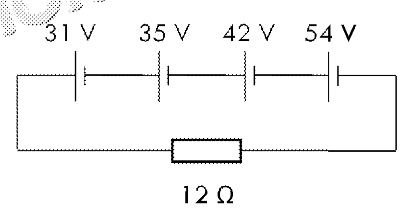
Bright spark

1. A circuit consists of 54 separate 18 V cells in parallel.

   These cells are connected to a 13 Ω resistor.

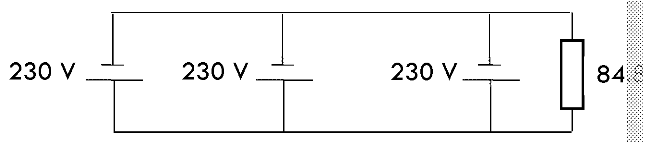
   Calculate the current through the resistor and a single cell.

2. Calculate the current in the circuit below.

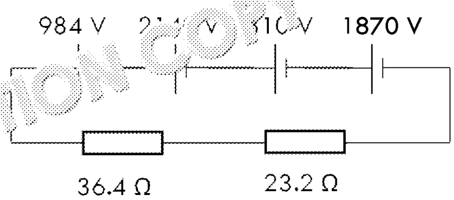


Charging up

3. Calculate the power dissipated by the circuit below.

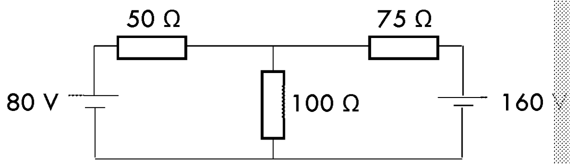


4. Calculate the power dissipated by the circuit below.

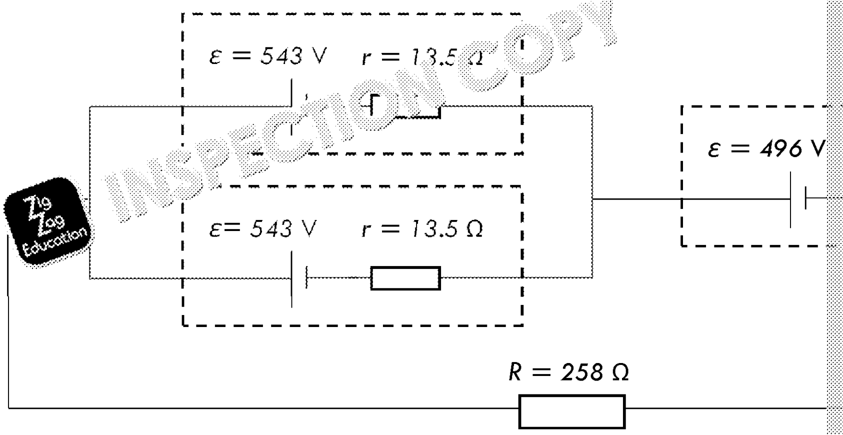


Shocking!

5. Calculate the current through each resistor in the circuit below.



6. Calculate the total power dissipated by the circuit below.



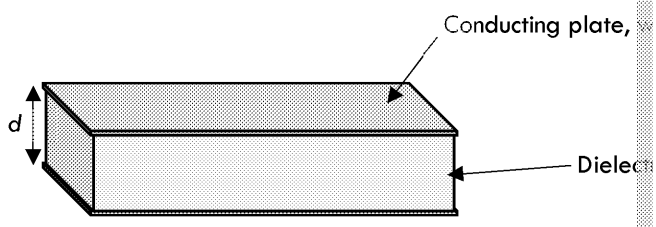
7. CAPACITANC

TOPIC 7: ELECTRIC AND MAGNETIC FIELDS

BACKGROUND

A capacitor is a component which stores chc rg , o d dissipates that charge over time.

A capacitor consists o el ctric (an insulating material) between two conducting s.



The capacitance of a capacitor is given by

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

$C =$ c
$Q =$ c
$V =$ p
$W =$ e
$A =$ o
$d =$ d

The energy stored by a capacitor is

$$W = \frac{1}{2}QV$$

Example 1

A capaci a capacitan 840 μF and stores a charge of 32 mC.

Calculate the energy stored by the capacitor.

e

$$W = \frac{1}{2}QV$$

but we need it in a form with charge and capacita difference.

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

so

$$W = \frac{1}{2}Q \times \frac{Q}{C} = \frac{1}{2}\frac{Q^2}{C}$$

Substituting in values gives

$$W = \frac{1}{2} \times \frac{(32 \times 10^{-3})^2}{840 \times 10^{-6}}$$

W = 0.61

Example 2
Calculate the capacitance of a metal sphere the size of Earth.

To do this we can use $C = \frac{Q}{V}$, but first we have to find
The potential at a distance r away from a charge is

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$

Putting this into the equation for capacitance gives

$$C = \frac{Q}{\left[\frac{Q}{4\pi\varepsilon_0 r}\right]}$$

Rearranging, this gives

$$C = \frac{Q}{Q} \times 4\pi\varepsilon_0 r = 4\pi\varepsilon_0 r$$

For a sphere the size of Earth, with $r = 6.37 \times 10^6$ m

$$C = 4 \times \pi \times 8.85 \times 10^{-12} \times 6.37 \times 10^6$$

$$\mathbf{C = 7.08 \times 10^{-4}\ F}$$

EXAM TIP
The potential of an electric field at a distance r away from a charge, Q, is

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$

This only applies in a vacuum and to conductors. In a [illegible]

$$V = \frac{1}{[illegible]}$$

This is the general form [illegible] equation. For a vacuum or conductor $\varepsilon_r = 1$.
This equation [illegible] potential in a capacitor.

EXAM TIP
r is used for distance when talking about electric fields and for internal resistance when talking about power sources.
Make sure you know which is being used!

QUESTIONS

Bright spark

1. The plates of a parallel plate capacitor have an area of 1.44 cm^2 and

   The capacitance of the capacitor is 963 μF.

   Calculate the relative permittivity of the dielectric i... he capacitor.

2. A capacitor has a capacitance of 18... F ... stores a charge of 81.4

   Calculate the potential di... ere... across the capacitor and the energy

Charging

3. A capa... has a capacitance of 249 μF. The capacitor has a resistan 41.6 mA flowing through it.

   Calculate the energy stored in the capacitor in J.

4. Using your knowledge of electric fields, show that the capacitance of tw given by

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

5. A storm cloud covers an area of 134 km^2 and is 40.6 km above the gro Calculate the capacitance of the storm cloud and the ground by modelli capacitor.

Shocking!

6. A capacitor consists of two cir... p...lel plates with a radius of 7.24 apart, and the dielec... ...een them has a relative permittivity of 6.8

   The ca... ...parallel plate capacitor with a dielectric is given b

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

   where ε_r is the relative permittivity of the dielectric between the two pl

   Calculate the energy stored in the capacitor in kJ when there is a poten across the two plates.

7. A spherical capacitor consists of a small metal sphere at the centre of a larger, hollow metal sphere, with a vacuum between, as shown.

   R_1 = radius of internal sphere = 2.43 cm

   R_2 = radius of external sphere = 6.09 cm

   Calculate the capacitance of the spherical ca...r.

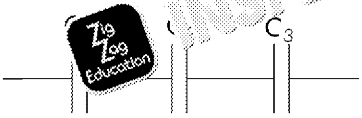
8. CAPACITORS IN SERIES AND

TOPIC 7: ELECTRIC AND MAGNETIC FIELDS

BACKGROUND

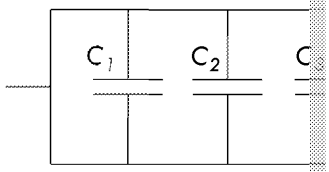
Capacitors are often only available in specific val… …apacitance, but a
or lower capacitance than those available. Li… …tors, capacitors can be
arrangements, allowing a wide ran… … …acitance from few capacitors w

For capacitors in series



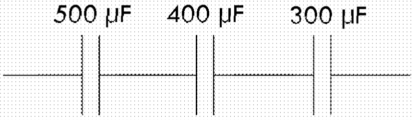
$$\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

For capacitors in parallel



$$C_{total} = C_1 + C_2 + C…$$

Example 1
Calculate the total capacitance of the arrangement of capacitors below.



For capacitors in series

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

Substituting in values gives

$$\frac{1}{C_{total}} = \frac{1}{500\times10^{-6}} + \frac{1}{400\times10^{-6}} …$$

$$\frac{1}{C_{total}} = …833$$

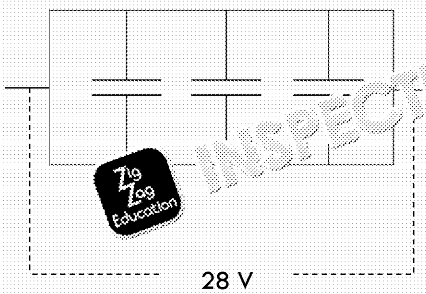
Rearranging for C_{total} gives

$C_{total} = 1.28 \times 10^{-4}$ F

$\mathbf{C_{total} = 128\ \mu F}$

As with resistors in parallel, you mi… rearranging and then substituting a… prefer to start by substituting in val… answer, but both methods need you … your calculator!

Example 2
Calculate the total energy of the arrangement of capacitors below.



For capacitors in parallel

$C_{total} = C_1 + C_2 + C_3$

Substitute in values

$C_{total} = 35 \times 10^{-3} + 42 \times 10^{-3} + …$

$C_{total} = …5$ mF

The capacitors act like one single, … stored by the arrangement of cap…

$$W = \frac{1}{2} C_{total} V^2$$

Substituting in values gives

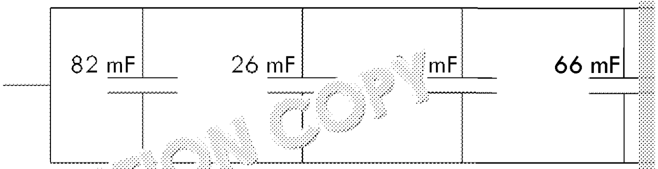
$$W = \frac{1}{2} \times 145 \times 10^{-3} \times 28^2$$

$\mathbf{W = 57\ J}$

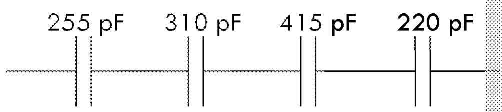
QUESTIONS

Bright spark

1. Calculate the combined capacitance of the arrangement of capacitors b

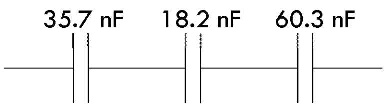


2. Calculate the combined capacitance in F of the arrangement of capacit

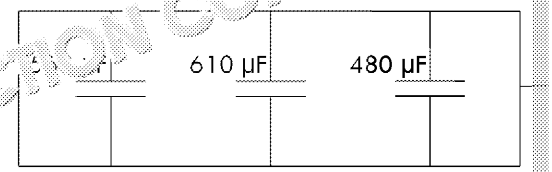


Charging up

3. The capacitors below can have a maximum potential difference of 500
   Calculate the maximum total charge stored in the capacitors.



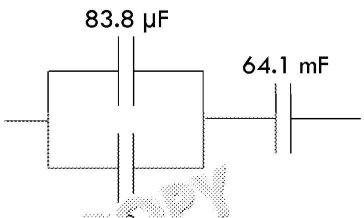
4. Calculate the potential difference across all of the capacitors below wh
   whole arrangement is 6.36 J.



Shocking!

5. The energy stored in the capacitors below is 65.0 J. 382 mC of charge
   total.

   Calculate the value of C.



6. The total capacitance of an arrangement of five capacitors is C_{total}.

   A capacitor with a capacitance of C_1 is in series with a capacitor with a c
   capacitors with capacitances of C_3 and C_4, which are in parallel with ea

   A capacitor with a capacitance of C_5 is in parallel with all of the other c

   Find an expression for C_1 in terms of the other capacitances in the circu

9. CHARGING AND DISC CAPACITORS

TOPIC 7: ELECTRIC AND MAGNETIC FIELDS

BACKGROUND

Capacitors charge and discharge exponentially.

	Discharging	Charging
Voltage	$V = V_0 e^{-\frac{t}{RC}}$	$V = V_0(1 - e^{-\frac{t}{RC}})$
Charge	$Q = Q_0 e^{-\frac{t}{RC}}$	$Q = Q_0(1 - e^{-\frac{t}{RC}})$
Current	$I = I_0 e^{-\frac{t}{RC}}$	$I = I_0 e^{-\frac{t}{RC}}$

I_0, Q_0 *and* V_0 each give the initial value of I, Q and V.
When charging, the initial value of Q and V is zero. In this case, Q_0 *and* V_0 are the maximum charge stored by the capacitor and the potential difference across the capacitor.

RC is known as the time constant of the capacitor, and is the time it takes for the capacitor to discharge to $e^{-1} = 0.37$ of its initial charge.

The half-life of the capacitor and coupled resistor – the time taken for the charge to fall to half its initial value – is given by $T_{1/2} = 0.69\ RC$.

Understanding and controlling the time taken for a capacitor to discharge c signals or store energy for use later.

Example 1
A capacitor is discharging through a resistor, as shown below.

Calculate the time taken for the potential difference across the capacitor to reach 10.0 V if the initial potential difference across the capacitor is 120 V.

We need to use an equation fo involves potential difference

$V = V_0 e^{-\frac{t}{RC}}$

Rearrange for t

$\frac{V}{V_0} = e^{-\frac{t}{RC}}$

$\ln\left(\frac{V}{V_0}\right) = -\frac{t}{RC}$

$t = -RC \times \ln\left(\frac{V}{V_0}\right)$

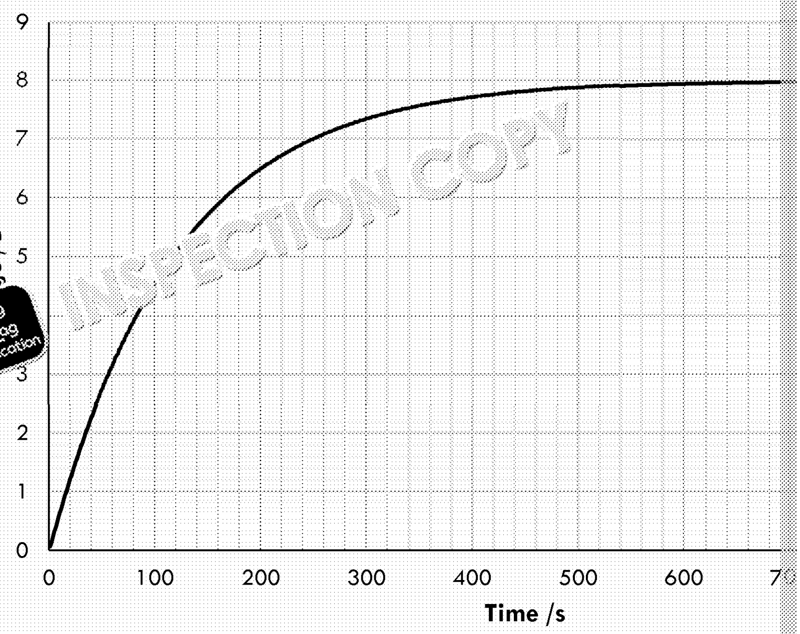
Substitute in values

$t = -2.80 \times 10^3 \times 700 \times 10$

$\boldsymbol{t = 4.87}$ **s**

Example 2

A capacitor charges through a resistor with a resistance of 30 kΩ, produc



Determine the capacitance of the capacitor.

This graph is approaching 8.0 C, which means this is Q_0.

We can either look for the half-life, $T_{1/2}$, *which, here, is the time taken to ch*

We know that $T_{1/2} = 0.69RC$, so

$$RC = \frac{T_{1/2}}{0.69} = \frac{80}{0.69}$$

$RC = 11$

Alternatively, we can look directly for RC, which is the time taken for a ca
0.37 Q_0, *or charge to* $(1 - 0.37)Q_0 = 0.63Q_0$

$0.63Q_0 = 0.63 \times 8.0 = 5.04$ C

This again gives us an RC of about 115 s!

We then use our value for RC to find C

$$C = \frac{RC}{R} = \frac{115}{30 \times 10^3}$$

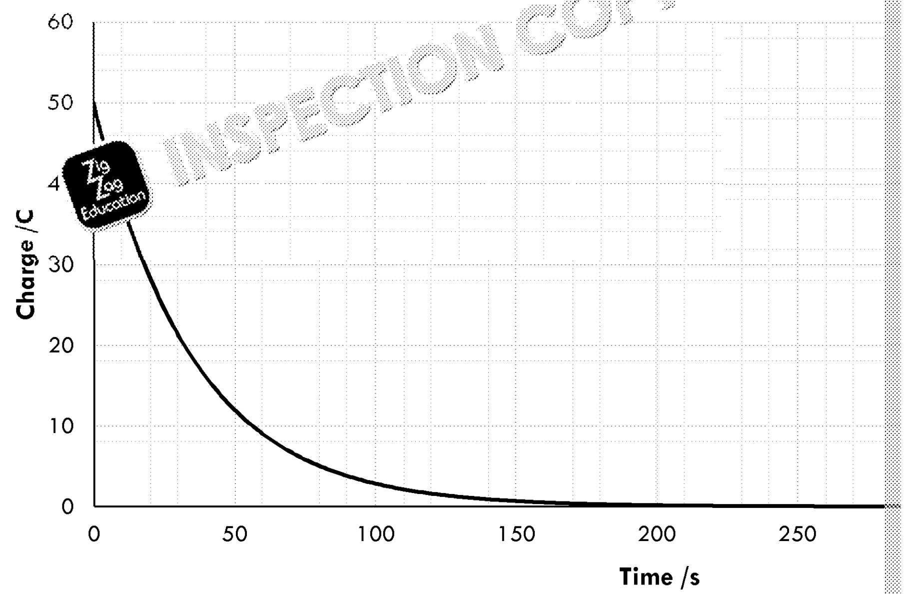
C = 0.0038 F = 3.8 mF

QUESTIONS

Bright spark

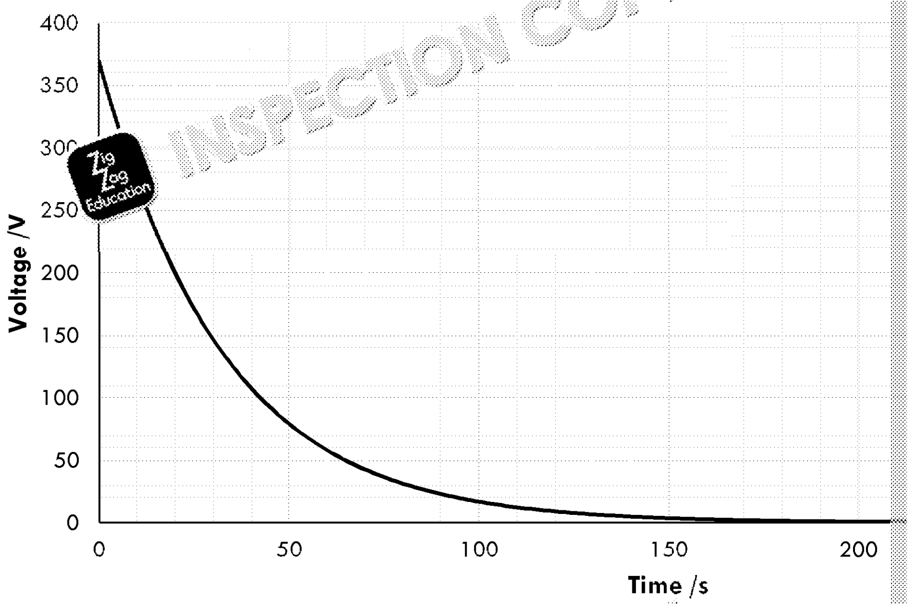
1. A capacitor discharges with a time constant of 38 s with an initial curre
   Calculate the current out of the capacitor after one minute.

2. Calculate the time constant and half-life of the capacitor shown in the g



Charging up

3. A 450 µF capacitor discharges through a resistor producing the graph



   Calculate the resistance of the resistor in kΩ.

4. A 400 µF capacitor discharges through a resistor from an initial potenti

   It takes 108 s to re

   Calculate the resistance of the resistor in kΩ.

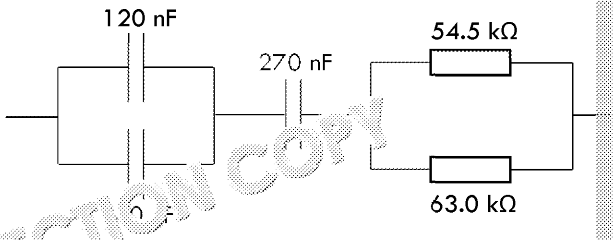
5. A capacitor is charged through a 24.5 kΩ resistor.

   After 64.3 s, the charge stored in the capacitor has reached 81.9 % of
   the capacitor.

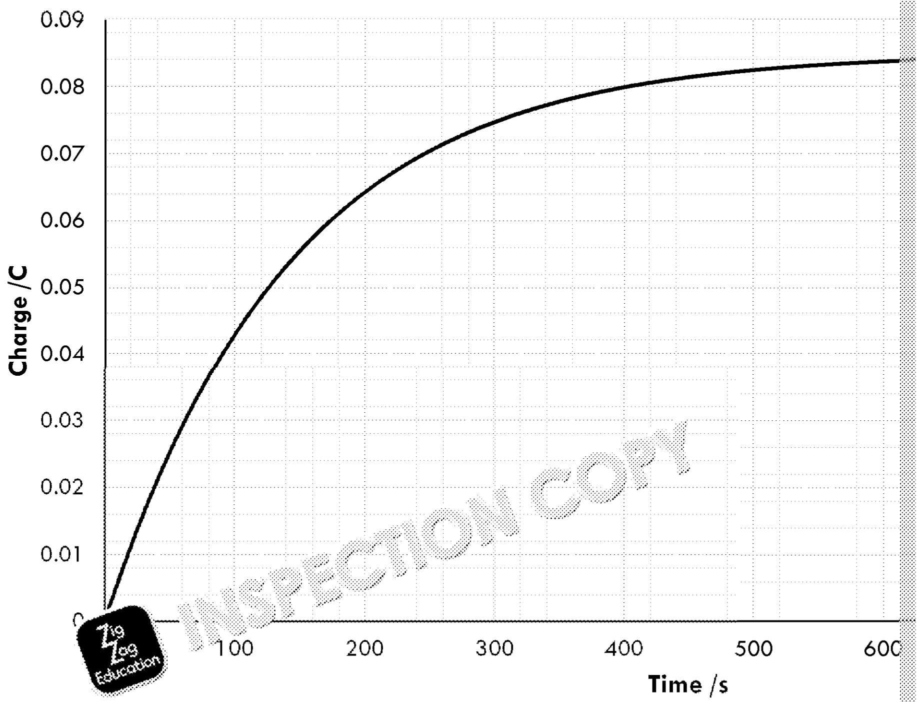
   Calculate the capacitance of the capacitor.

Shocking!

6. Calculate the time taken for the charge in the capacitors below to reac
of 37.8 C.



7. The gr[...]elow shows a capacitor charging through a resistor with a r



a) After what time will 1.81 J of energy be stored?

b) Calculate the percentage of the potential difference across the ca
compared to its initial value.

10. TRANSFORME

TOPIC 7: ELECTRIC AND MAGNETIC FIELDS

BACKGROUND

A transformer consists of two coils of wires around an iron core.

A transformer can be used to increase or decrease a potential difference; this is because transmitting power at low currents reduces power loss, and appliances require a specific potential difference to function.

The relationship between the number of turns in the coils of a transformer and the potential difference across the coils is

$$\frac{N_s}{N_p} = \frac{V_s}{V_p}$$

N_p = nu
N_s = nu
V_p = po
V_s = po
I_p = cu
I_s = cu

Each coil of a transformer dissipates energy, with the power transferred by

$$power = IV$$

Example 1
Electricity is transmitted at a potential difference of 11 kV.

Electrical substations convert this to the 230 V used in homes and businesses.
The secondary coil in one such substation has 500 turns.

Calculate the number of turns in the primary coil.

Use $\frac{N_s}{N_p} = \frac{V_s}{V_p}$

with $N_s = 500$, V_s = 230 V and V_p =

We need to rearrange for N_p

$N_p = N_s \frac{V_p}{V_s}$ *[multiply both sides*

Then substitute in values

$N_p = 500 \times \frac{11 \times 10^3}{230}$

$\boldsymbol{N_p}$ **= 23900 turns**

Example 2
A transformer is 80 % efficient.
The primary coil of a transformer is connected to a 50 V power supply, and has 80 A running through it.

The secondary coil provides 90 V.

Calculate current through the secondary coil.

Efficiency is given by

$efficiency = \frac{power\ output}{power\ input}$

so for a transformer

$efficiency = \frac{I_s V_s}{I_p V_p}$

with efficiency = 80 % = 0.8, V_p =
I_p = 80 A and V_s = 90 V.

Rearrange for I_s

$I_s = efficiency \times \frac{I_p V_p}{V_s}$

$I_s = 0.8 \times \frac{80 \times 50}{90}$

$\boldsymbol{I_s = 36}$ **A**

EXAM
Efficie
percen
decima

For ex
equiva

Example 3

A transformer is 75 % efficient. The potential difference across the primary coil is 300 V. The resistance of the primary coil is 100 Ω.

The primary coil has 80 turns and the secondary coil has 15.

Calculate the current i secondary

As in Example 2, we can use

$$efficiency = \frac{I_s V_s}{I_p V_p}$$

but we don't have anything in the corr
$efficiency = 75\ \% = 0.75$, $V_p = 300$ V
$N_s = 15$.

IV c a gives us the power transfe
be expressed as I^2R or $\frac{V^2}{R}$.

We can write

$$efficiency = \frac{P_s}{P_p} = \frac{I_s V_s}{V_p^2 / R_p}$$

which we can rearrange for I_s

$$I_s = efficiency \times \frac{V_p^2}{R_p V_s}$$

But we don't have V_s! Instead, we nee

$$\frac{N_s}{N_p} = \frac{V_s}{V_p}$$

which rearranges for V_s

$$V_s = \frac{V_p N_s}{N_p}$$

Substituting values gives

$$V_s = 300 \times \frac{15}{80}$$

$$V_s = 56.25 \text{ V}$$

and substituting values into our earlier

$$I_s = efficiency \times \frac{V_p^2}{R_p V_s}$$

$$I_s = 0.75 \times \frac{300^2}{100 \times 56.25}$$

$$\mathbf{I_s = 12\ A}$$

QUESTIONS

Bright spark

1. A transformer has 350 V across its primary coil, which has 240 turns.

   The secondary coil has 140 turns.

   Calculate the potential difference across the seco... y coil.

2. A transformer has a current of 13... through its primary coil ... secondary coil.

   The potential diff... across the primary coil is 7.5 kV and across th...

   Calcul... e...iciency of the transformer.

Charging up

3. A transformer is 94.2 % efficient. The potential difference across the s... The power supplied to the primary coil is 6.50 kW.

   Calculate the current in the secondary coil.

4. The number of turns in the primary coil of a transformer is 400 and the ... secondary coil is 700.

   The current through the primary coil is 84.3 A and the current through th...

   Calculate the efficiency of the transformer.

5. The power supplied to the primary coil of a transfo...er is 850 W.

   The efficiency of the transformer is 90.0 %.

   The resistance of the secon... ...il is 77.3 Ω.

   Calculate the cu... ...gh the secondary coil.

Shocking!

6. There is a potential difference of 230 V across the primary coil of a tr... of 34.0 A running through it. The primary coil has 180 turns.

   The secondary coil of the transformer has 66.7 % more turns than the p... resistance of 77.8 Ω.

   Calculate the efficiency of the transformer.

7. In a step-down transformer, one of the coils has 1.76 times as many coi...

   The primary coil of a transformer has a resistance of 640 Ω. The prima... The transformer is 72.0 % efficient.

   Calculate the current in the secondary transfor...

11. ELECTROMAGNETIC PH

TOPIC 7: ELECTRIC AND MAGNETIC FIELDS

BACKGROUND

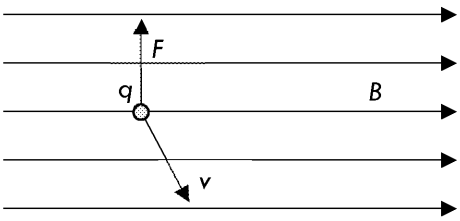
Electricity and magnetism have a strange connection in that an electric current can generate magnetic fields, and magnetic fields can generate currents. Meanwhile, an electric current – or rather, moving charge – in a magnetic f

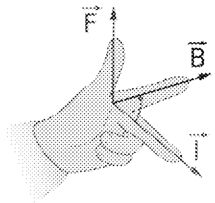
A moving charge in a magnetic field

The force on a moving charge in a magnetic field is given by

$$F = Bqv \sin \theta$$

Fleming's left hand rule gives the direction of the force felt by a moving





Hold your left ha

- Your thumb r **force felt.**
- Your first fing represents th **of the magn**
- Your second f represents th **of positive cu**

Magnetic fields and moving charges

A moving charge, or a current, **generates a magnetic field.**

The direction of the magnetic field can be determined by the **right hand gri** your right thumb out and curl your fingers around; your thumb is the directio current and fingers point in the direction of the generated magnetic fie

Faraday's law

Faraday's law describes how an **e.m.f. is generated across a conductor** as through a magnetic field, or as the magnetic field changes around the cond

The e.m.f. induced in the conductor is proportional to the rate of change of magnetic flux in the conductor – the magnetic field passing through a cross-section of the conductor.

Lenz's law

Lenz's law states that any change in e.m.f. or magnetic field will oppose the source of that change.

Example 1

A copper ball is passed through a copper tube.

It takes significantly longer for the ball to fall through the tube than it would had it just been dropped in free space.

Explain this effect.

This effect isn't to do with friction, air-re in the tube, as you might expect, but ra ball and tube are made of.

As the copper ball passes through the tu conductors move **relative** to each other a magnetic field.

The copper ball falls through the magn tube, so that it experiences a force.

Lenz's law states that the change brou field will oppose the change, so that th

Example 2

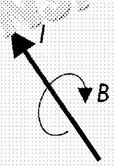
A solenoid consists of a wire wrapped into a coil.

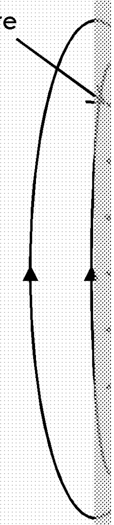
A current flows through the solenoid, generating a magnetic field.

Draw the magnetic field around a solenoid, explaining its shape.

In the diagram, current is travelling right to left across the front edge of the solenoid, and left to right on the back edge.

A single straight wire produces a magnetic field around it as shown below.





Multiple wires placed next to each other (or a single wire wrapped around itself) would produce a single magnetic field that was the sum of each individually produced magnetic field.

Using the right hand grip rule, the magnetic field travels up on the outside of the solenoid and down on the inside of the solenoid.

QUESTIONS

Bright spark

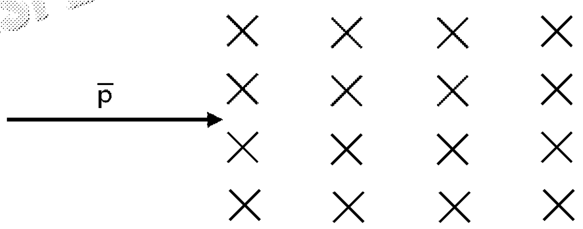
1. Two wires lie next to each other, with currents facing in the same directi

   Draw the magnetic field generated around both wires, and explain its s

2. An antiproton travels through a magnetic field as shown below.

   The magnetic field faces **into the page**.

   Complete the diagram to show the path of the antiproton as it travels th



Charging up

3. As a plane flies, it passes through a magnetic field, which points directly

   Using Fleming's left hand rule, explain why the plane experiences a forc backwards due to Earth's magnetic field.

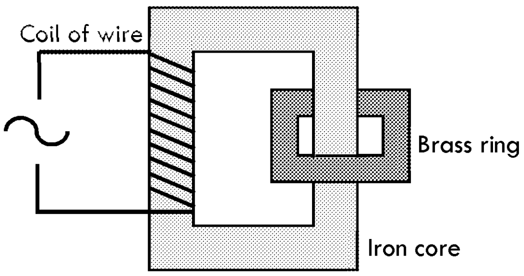
4. Two identical copper balls are dropped through two metal tubes.

   Both tubes are identical, except one is made of copper and one is made Copper is a better conductor than steel.

   Describe and explain the effect this has on the balls as they fall through

Shocking!

5. A set-up is shown below.



   Describe and explain the effect of an AC current being applied through

6. A Halbach array is an arrangement of magnets that generates a strong the array, and a weak or zero magnetic field on the other side.

   A Halbach array is shown below, with the arrows showing the direction o magnet.

   Predict which side of the array will produce a strong magnetic field, ex

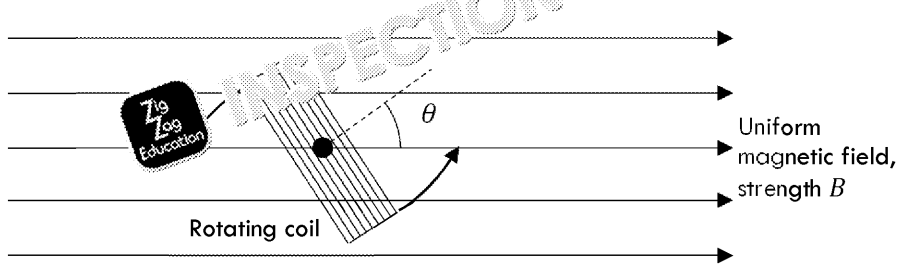
→	↑	←	↓	→	↑	←	↓	→	↑	←	↓

12. ELECTRICITY GENE

TOPIC 7: ELECTRIC AND MAGNETIC FIELDS

BACKGROUND

Electromagnetic induction is the production of a potential difference across a magnetic field. Power stations rotate coils of wire in magnetic fields to gene



Faraday's law states that the magnitude of the e.m.f. induced in a coil is

$$\varepsilon = -\frac{d(N\Phi)}{dt}$$

This equations states that the potential created in a coil is equal to the change in magnetic flux linkage through the coil ($N\Phi$) over time, where

$$N\Phi = BAN\cos\theta$$

This means that the magnetic flux linkage is related to the strength of the magnetic field, the area of the coil and the number of turns in the coil.

Lenz's law states that any e.m.f. induced will oppose the change that induce the e.m.f., which is why there is a negative sign in Faraday's law.

A coil rotating uniformly in a magnetic field will have an induced e.m.f. of

$$\varepsilon = BAN\omega\sin\omega t$$

This relates the change in magnetic flux linkage of the coil to the rate the coil is rotating at.

Example 1
A coil has 80 turns and a cross-sectional area of 0.85 m^2.

The coil is in a magnetic field with magnetic field strength 36 mT.

The coil's cross-section initially makes an angle of 20° to the magnetic field.

The coil then rotates over 15 s so that its cross-section makes an angle of 65° to the magnetic field.

Calculate the e.m.f. induced in the coil.

Use $\varepsilon = -\frac{d(N\Phi)}{dt} = -\frac{\Delta(N\Phi)}{\Delta t}$

but instead of being given $\Delta\Phi$,

$N\Phi = BAN\cos\theta$

$\Delta\Phi$ is the difference in flux bet

$\Delta\Phi = BA(\cos\theta_2 - \cos\theta_1)$

$\Delta\Phi = 36 \times 10^{-3} \times 0.85 \times (\cos$

$\Delta\Phi = -0.0158$ T m^2

Putting this into our original equ

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

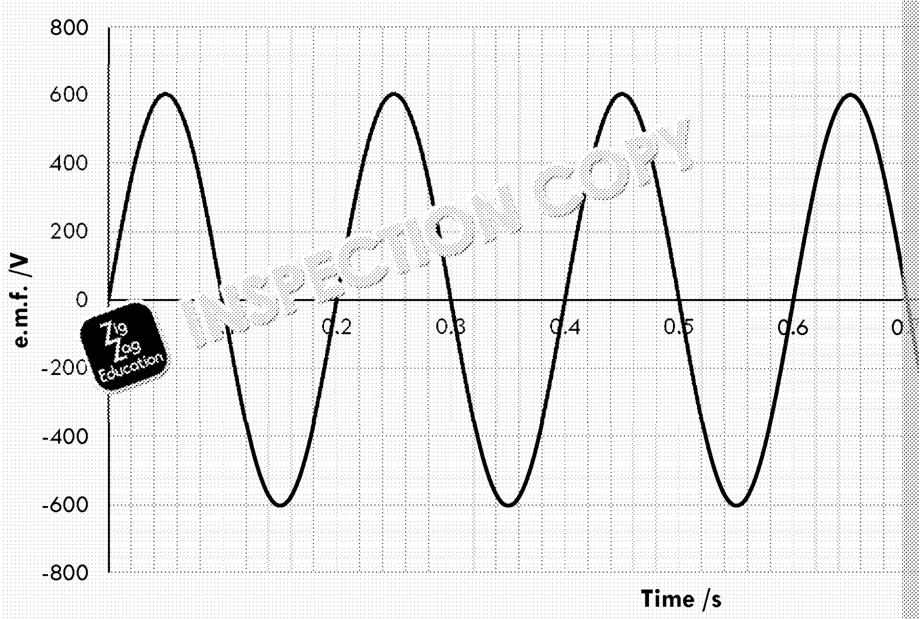
$\varepsilon = -80 \times \frac{-0.0158}{15}$

$\varepsilon = 0.084$ V

EXAM T
A nega
that the
way fro

Example 2

A coil rotates in a magnetic field, producing the graph below.



The flux of the coil, Φ, is 0.0128 T m^2.

Calculate the number of turns in the coil.

From the graph, peak e.m.f. = *615* V and the period of the e.m.f. is 0.2 s.

The period of a sine wave is 2π radians.

Here we have $\sin \omega t$, so $\omega t = 2\pi$

$$\omega = \frac{2\pi}{t} = \frac{2\pi}{0.2}$$

$\omega = 31.$ [illegible] $\mathrm{s^{-1}}$

The peak of the e.m.f. at $\theta = 0$ or $\omega t = \frac{\pi}{2}$ is $\varepsilon = BAN\omega$

$BA = \Phi$, which is given, and we found ω in our last step

So rearranging for N gives

$$N = \frac{\varepsilon}{\Phi\omega}$$

Substituting in values gives

$$N = \frac{615}{0.0128 \times 31.4}$$

$\boldsymbol{N = 1530}$ **turns**

EXAM T
When fi
area or
to worry
Faraday

QUESTIONS

Bright spark

1. A coil of wire with a cross-sectional area of 3.6×10^{-3} m² and 200 turn[s] of magnetic field strength 19 μT.

   The cross-section of the wire makes an angle of 0.40 rad to the magne[tic]

   Calculate the magnetic flux linkage in the coil.

2. A coil with 38 turns and a cross-sectional area of 12.6 cm² is perpendic[ular] field. The magnetic field increases from 14.1 mT to 93.7 mT over 60.0 [illegible]

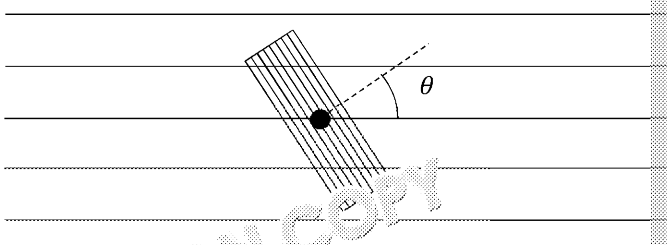
   Calculate the e.m.f. induced in the coil.

3. A coil has 120 coils and a cross-sectional area of 728 cm². The coil ro[tates] magnetic field strength 407 mT at a rate of 170 revolutions per minute.

   Calculate the e.m.f. generated in the coil one minute after it starts rotat[ing] cross-section facing the magnetic field.

Charging up

4. The diagram below shows a coil of wire in a uniform magnetic field. Th[e]

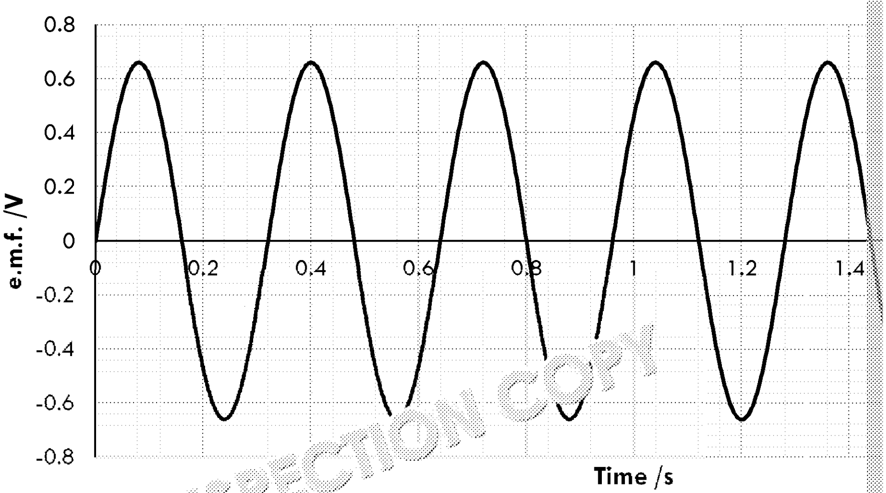


   At $t = 0$, $\theta = 0°$. At $t = 2.5$[illegible] $= 36°$.

   The e.m.f. induced in the coil is 130 mV.

   Calculate the cross-sectional area of the coil.

5. The graph below shows the e.m.f. of a coil rotating in a magnetic field.



   Calculate the angular frequency of the coil.

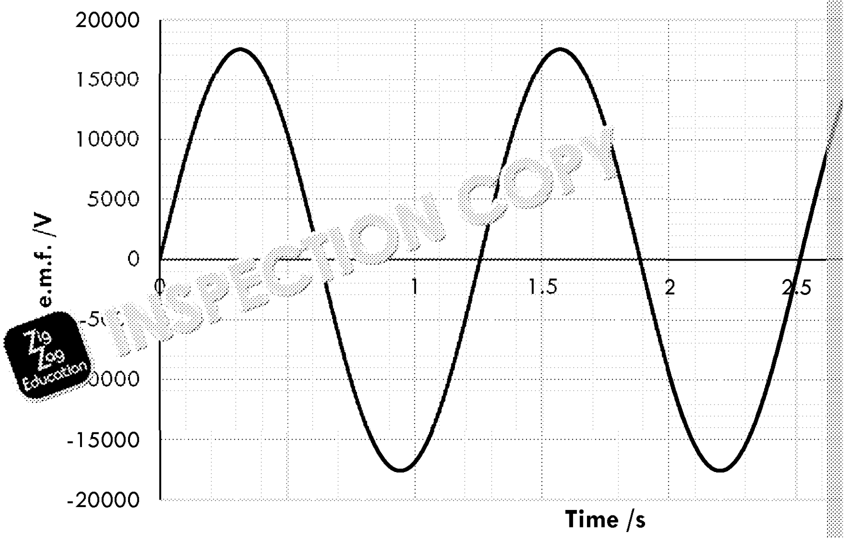
6. A coil has 50 turns and a cross-sectional area of 300 mm² and is place[d] perpendicular to a magnetic field of magnetic field strength 20 mT.

   The coil is pulled 15 cm up and out of the magnetic field, inducing an e.[m.f.]

   Calculate the speed at which the coil is moved.

Shocking!

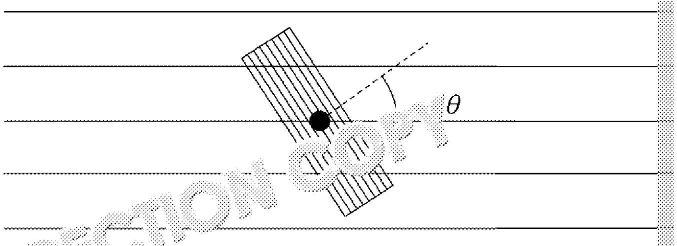
7. The graph below shows the e.m.f. of a coil rotating in a magnetic field.



The number of turns in the coil is 3000 and the cross-sectional area of th

Calculate the magnetic field strength.

8.



The co n above rotates at $\omega = 2.88$ rad s^{-1} and the number of tu

The e.m.f. induced in the coil is 55.6 mV as the coil moves from maximu linkage.

Calculate the effective area of the coil presented to the magnetic field.

13. OSCILLOSCOP

TOPIC 7: ELECTRIC AND MAGNETIC FIELDS

BACKGROUND

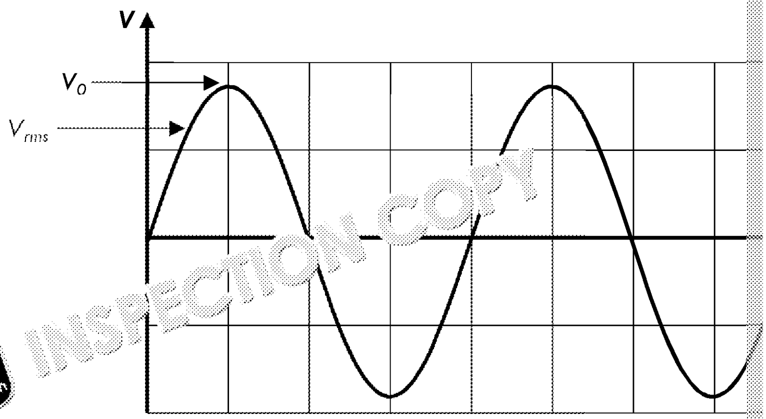
An alternating current can be discussed in terms of its frequency, peak voltage and root mean square voltage.

$$V_{rms} = \frac{V_0}{\sqrt{2}}$$

$$I_{rms} = \frac{I_0}{\sqrt{2}}$$

An oscilloscope can be used to show an alternating current on a screen.

The oscilloscope needs to be set up to show an appropriate potential differe and an appropriate time per division (horizontally).



Being able to describe and analyse alternating currents lets physicists and engineers know about the energy the National Grid is supplied with, and how it needs to be modulated for appliances.

Example 1
Electricity for domestic uses in the UK has a root mean square potential difference of 230 V.

Calculate the peak potential difference of domestic electricity in the UK.

We use $V_{rms} = \frac{V_0}{\sqrt{2}}$

which rearranges to

$V_0 = \sqrt{2}V_{rms}$

Substituting in values gives

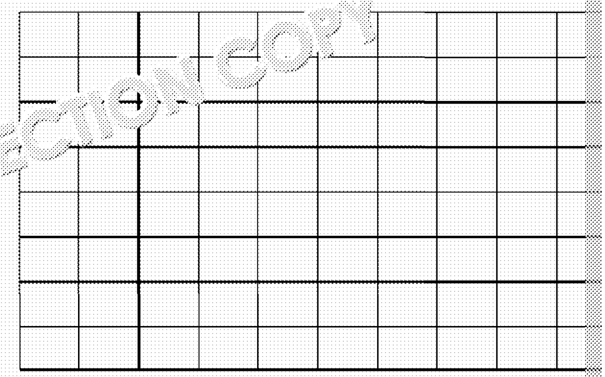
$V_0 = \sqrt{2} \times 230$

$\boldsymbol{V_0 = 325}$ **V**

Example 2
An oscilloscope screen can be seen below.

State how the oscilloscope should be set up to show a single wavelength of
frequency of 50 Hz and a peak current of 4.0 A.

Draw the pattern you would see on the oscilloscope.



The oscilloscope is split up horizontally into 10 sections – there are 10 divis

The period of a wave with a frequency of 50 Hz is given by

$T = \frac{1}{f} = \frac{1}{50} = 0.02$ s

This means that to show a single wavelength on the oscilloscope, the 10 div
represent 0.02 s.

So, a single division represents $\frac{0.02}{10} = 0.002$ s div^{-1}.

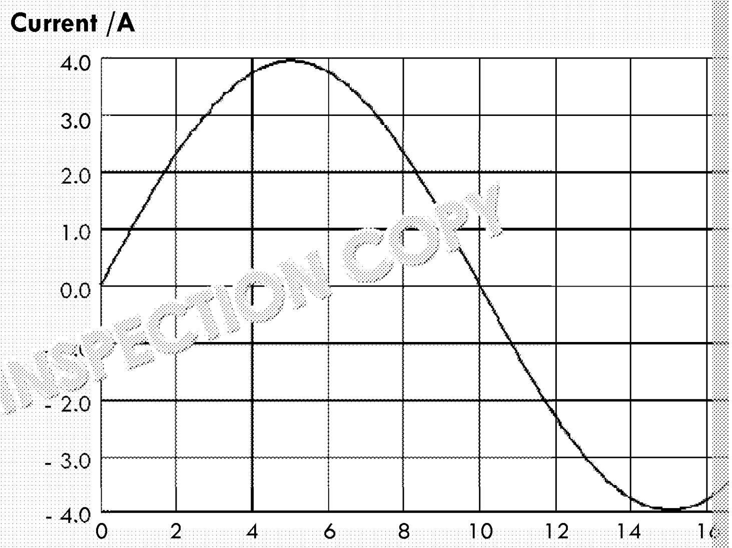
This is called the **time base setting**.

The oscilloscope is split up vertically into eight sections – there are eight di
The peak current is the highest amplitude of the current.

This is only in the positive direction, so while I_0 is 4.0 A, we actually need e
So the **current base setting** is $\frac{8.0}{8} = 1.0$ A div^{-1}.

(These are only the minimum required settings -2.0 A div^{-1}, for example, w
but it's important to show the wave as large and in as much detail as possi

On the oscilloscope, this would be seen as



Example 3
The uncertainty of an oscilloscope will vary from model to model. The uncertainty will usually be given somewhere on the oscilloscope or in a handbook.

For a particular oscilloscope, the uncertainty in horizontal and vertical divisions is ±0.1 divisions. An AC voltage is inputted to the oscilloscope.

The time base setting is 0.4 ms div^{-1}. A single cycle of the AC voltage appears over 6.0 div.

The voltage base setting is 0.5 V div^{-1}. The peak-to-peak voltage is measured over 3.5 div.

Calculate the frequency and voltage of the AC voltage, including uncertainties.

The period of the AC voltage is given by

$T = \text{number of divisions for one cycle} \times \text{time}$

$T = 6.0 \times 0.4 \times 10^{-3}$

$T = 2.4$ ms

The percentage uncertainty in the period is

$\text{percentage uncertainty of period} = \frac{\text{uncertainty}}{\text{number of}}$

$\text{percentage uncertainty of period} = \frac{0.1}{6.0} \times 1$

$\text{percentage uncertainty of period} = 1.7\ \%$

The frequency of the voltage is given by

$f = \frac{1}{T}$

$f = \frac{1}{2.4 \times 10^{-3}}$

$f = 417$ Hz

The percentage uncertainty is the same for so the percentage uncertainty of the frequ corresponds to $417 \times 0.017 = \pm 7.0$ Hz.

The peak-to-peak voltage is given by

$V = \text{number of divisions} \times \text{voltage base set}$

$V = 3.5 \times 0.5$

$V = 1.8$ V

The percentage uncertainty of the voltage

$\text{percentage uncertainty of voltage} = \frac{\text{uncert}}{\text{numb}}$

$\text{percentage uncertainty of voltage} = \frac{0.1}{3.5} \times$

$\text{percentage uncertainty of voltage} = 2.9$

This corresponds to $1.8 \times 0.057 = \pm 0.05$

So $\boldsymbol{f = 417 \pm 7.0}$ **Hz** and $\boldsymbol{V = 1.8 \pm 0.05}$

QUESTIONS

Bright spark

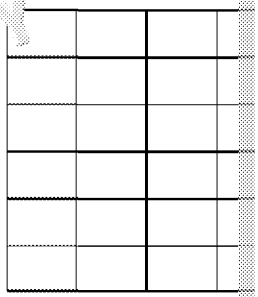
1. Several countries use mains electricity with $V_{rms} = 110$ V.

   Calculate the peak-to-peak potential difference of the mains electricity

2. A student wants to use an oscilloscope to show an AC current with a peak current of I_0 = ?.4 and a period of $T = 12.5$ ms.

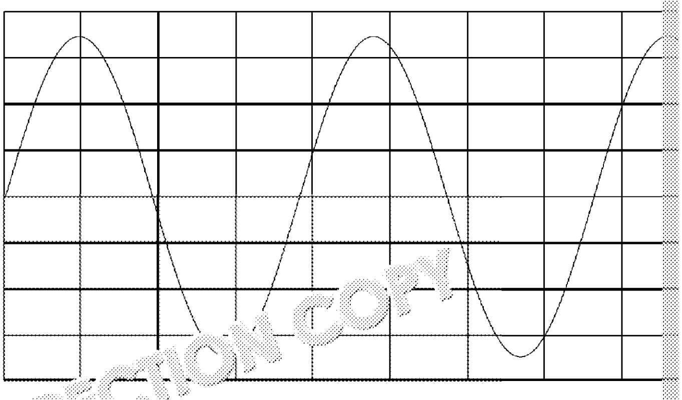
   Describe the minim... required to show two ful... es ... current.

   The scr... the oscilloscope is shown on the right.



Charging up

3. An oscilloscope is set up with a time base setting of 0.2 ms div^{-1} and a v 0.8 V div^{-1}. An AC voltage is produced on the oscilloscope screen, as s



   Calculate the ... peak voltage of the AC voltage.

Shocking!

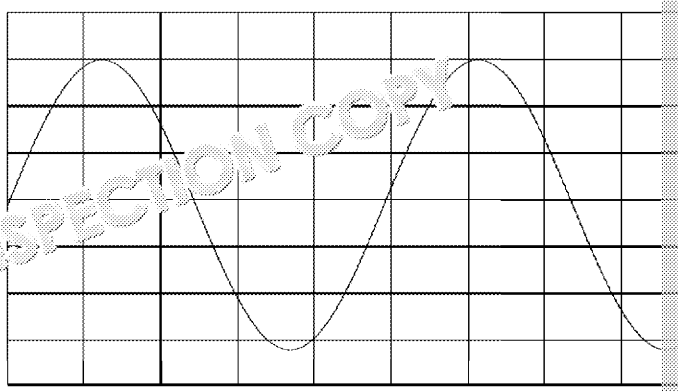
4. An alternating current is displayed on an oscilloscope, with a peak curr base setting is 3.0 A. The uncertainty of the oscilloscope is ±0.5 div.

   Calculate the uncertainty of the root mean square current.

5. The time base setting on an oscilloscope is 1.5 ms div^{-1}. The voltage b

   The uncertainty for the time setting is ±*0.2* div. The uncertainty for the v

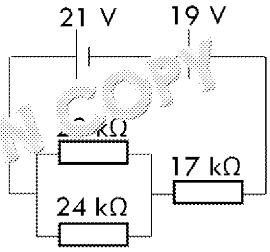
   An AC potential difference is inputted to the oscilloscope, and the scree



   Calculate the frequency and peak potential difference of the AC poten absolute uncertainties.

EXAM-STYLE QUESTIONS

1. The diagram below shows a circuit.



   (a) Calculate the combined resistance of the three resistors.

   (b) The 21 V power source has an internal resistance of 0.68 Ω.

   The 18 V power source has an internal resistance of 0.34 Ω.

   Calculate the current through the power sources to an appropriate numbe

   (c) Calculate the power dissipated by the total circuit.

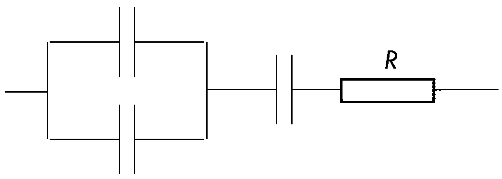
2. A block of tungsten has a square cross section with a side length of 8.3 cm, an
The resistance of the block is 1.1×10^{-4} Ω.

   (a) Calculate the resistivity of tungsten.

   (b) The tungsten is stretched out to a new length of [illegible] m.
   Calculate the resistance of the new tungsten wire.

   (c) The wire transmits a power of 45 W, with a potential difference of 92 V
   Calculate the power dissipated by the wire.

3. Three identical parallel-plate capacitors and one resistor are placed in the ar



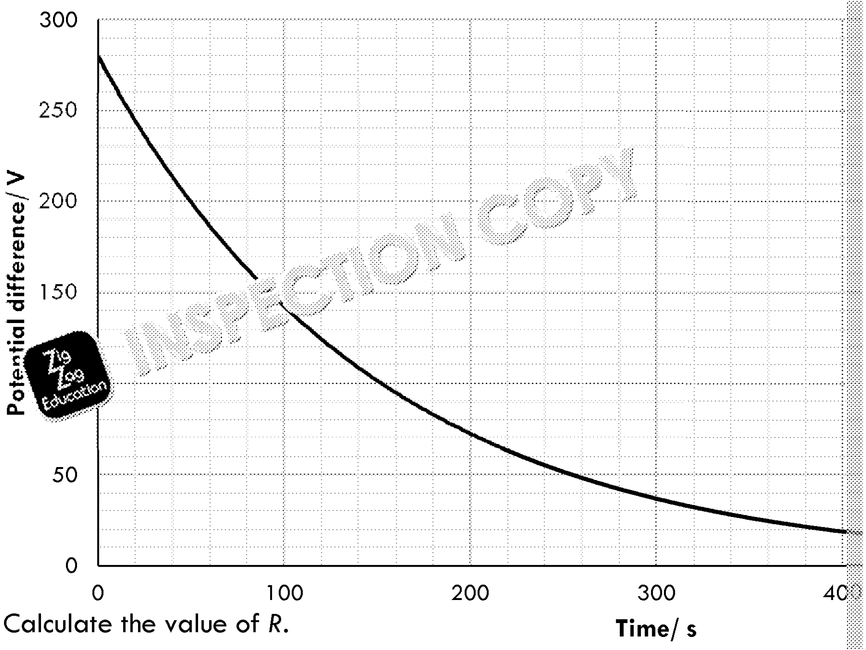
   (a) Each of the capacitors has a capacitance of 850 μF.

   Each plate of the capacitors is a circle with a radius of 4.1 mm, and the p

   Calculate the relative permittivity of the dielectric between the plates.

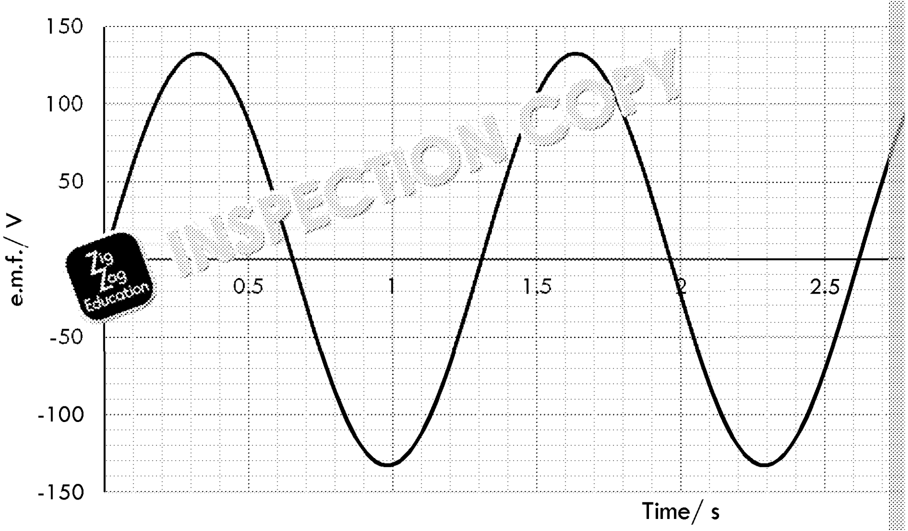
   (b) Calculate the total capacitance of the arrangement seen in the diagram a

(c) The capacitors discharge through the resistor, producing the graph seen b



Calculate the value of R.

4. A coil with a cross-sectional area of 0.16 m^2 and 320 turns rotates in a magne strength B, producing the graph seen below.



(a) Calculate the angular frequency of the coil.

(b) Calculate the value of B.

(c) The e.m.f. produced is put through a transformer ... 75 turns on the prim secondary coil.

The current through the prim... the transformer is 210 mA, and the

Calculate the curr... the secondary coil of the transformer.

(d) Th...nti... difference across the secondary coil of the transformer is di 8 ... divisions and 12 horizontal divisions.

Describe how the oscilloscope should be set up to show a single waveleng

ANSWERS

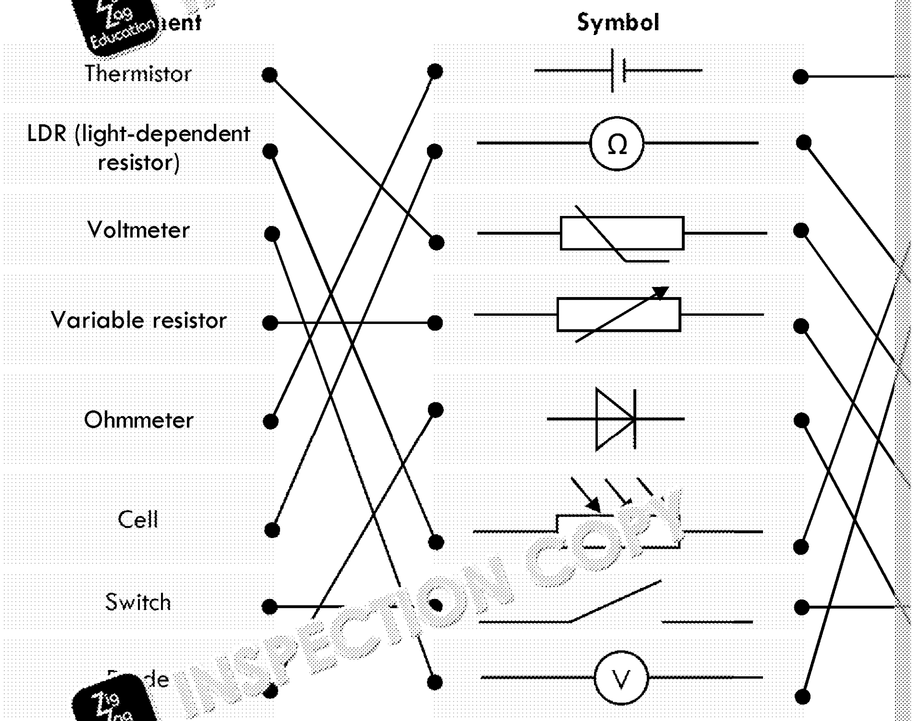
GCSE POP QUIZ

1. Current is the rate of flow of **charge**.
   Potential difference is the energy transferred to a charge.
   For a given potential difference, a lower resistance component will have a **higher** current flowing thro

2. $Q = It$

   $I = \frac{Q}{t} = \frac{23}{60} = 0.38$ A

3. Circuit A – no, the cir
   Circuit B – yes, the ci
   difference source and
   Circuit C – no, there is

4. 

5. $V = IR$

   $R = \frac{V}{I} = \frac{52}{850 \times 10^{-3}} = 61\ \Omega$

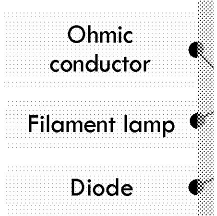
6. a) $R_{total} = R_1 + R_2 + R_3 = 630 + 680 + 820 = 2130\ \Omega$
   b) The resistance would decrease as each branch of the circuit would have less current, requiring less potential difference to push the current through each branch.

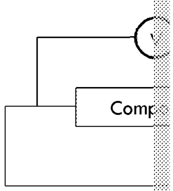
7. $I_{in} = I_{out}$

   $8.5 + 6.3 = 4.1 + I$

   $I = 8.5 + 6.3 - 4.1 = 10.7$ A

8. Kirchhoff's first law states that the current into a junction equals **the current out of the junction**.
   Kirchhoff's second law states that the potential difference gained in a power source is equal to the **potential difference lost in the circuit**

9. 



11. a) $P = \ldots(190 \times 10^{-3})^2 \times 220 = 7.9$ W
    b) $E = QV$

    $V = \frac{E}{Q} = \frac{370}{8.3} = 45$ V

12. Transformers are used to increa reduce power loss in cables. Tr voltage of electricity for use in h

13. Generate electricity for the Nat convert motion to electricity for li vibrations to signals

1. RESISTORS IN SERIES AND IN PARALLEL

Bright spark

1. $R_{total} = R_1 + R_2 + R_3 + R_4 + R_5$

   $R_{total} = 3.98 + 2.22 + 4.01 + 3.53 + 2.80$

   $R_{total} = 16.5\ \Omega$

2. $\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}$

   $R_{total} = \frac{1}{1/R_1 + 1/R_2 + 1/R_3 + 1/R_4 + 1/R_5}$

   $R_{total} = \frac{1}{1/\ldots\ 1/2\ldots\ 1/3.53 + 1/2.80}$

   $R_{total} =$

Charging up

3. $R_{total} = R_1 + R_{parallel}$

   $\frac{1}{R_{parallel}} = \frac{1}{R_2} + \frac{1}{R_3}$

   $R_{parallel} = \frac{1}{1/R_2 + 1/R_3}$

   $R_{total} = R_1 + \frac{1}{1/R_2 + 1/R_3}$

   $R_{total} = 34.9 + \frac{1}{1/78.2 + 1/56.4}$

   $R_{total} = 67.67\ \Omega$

   $V = IR_{total}$

   $I = \frac{V}{R_{total}}$

   $I = \frac{30.0}{67.67}$

   $I = 443$ mA

4. $V = IR_{total}$

   $R_{total} = \frac{V}{I}$

   $R_{total} = \frac{180}{780 \times 10^{-3}}$

   $R_{total} = 230.8\ \Omega$

   $R_{total} = R_{series} + R_{parallel}$

   $R_{parallel} = R_{total} - R_{series}$

   $R_{parallel} = 230.8 - 114$

   $R_{parallel} = 116.8\ \Omega$

   $\frac{1}{R_{parallel}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

   $R_1 = \frac{1}{1/R_{parallel} - 1/R_2 - 1/R_3}$

   $R_1 = \frac{1}{1/116.8 - 1/356 - 1/383}$

   $R_1 = 318\ \Omega$

Shocking!

5. $V_{total} = V_1 + V_2$

   $V_1 = V_{total} - V_2$

   $V_1 = 185 - 96.5$

   $V_1 = 88.5$ V

   $V = IR$

   $I = \frac{V}{R}$

   $I = \frac{96.5}{32.0}$

   $I = 3.016$ A

   $V_1 = IR_{total}$

   $R_{total} = \frac{V_1}{I}$

   $R_{total} = \frac{88.5}{3.016}$

   $R_{total} = 29.34\ \Omega$

   $\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

   $\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_4 + R_5}$

   $\frac{1}{R_4 + R_5} = \frac{1}{R_{total}} - \frac{1}{R_1} - \frac{1}{R_2}$

   $R_4 = \frac{1}{1/R_{total} - 1/R_1 - 1/\ldots}$

   $R = \frac{1}{1/29.34 - 1/76.0 - \ldots}$

   $R = 141\ \Omega$

6. $V = IR$

   $V_{original} = 5 \times (12 + \ldots$

   $V_{original} = 20 \times (12 \ldots$

   $26 = 0.25 \times (R_1 + \ldots$

   $5 \times (12 + R_1) = 20\ldots$

   $60 + 5R_1 = 240 + \ldots$

   $R_1 = 36 + 4R_2$

   $26 = 0.25\ (36 + 4\ldots$

   $26 = 9 + 1.25R_2$

   $\boldsymbol{R_2 = 13.6\ \Omega}$

   $R_1 = 36 + 4R_2$

   $\boldsymbol{R_1 = 90.4\ \Omega}$

2. POWER

Bright spark

1. $P = \frac{V^2}{R}$

$R = \frac{V^2}{P}$

$R = \frac{230^2}{40}$

$R = 1300\ \Omega$

2. $P = I^2R$

$W = Pt$

$W = I^2 \ldots$

$W = (77.1 \times 10^{-3})^2 \times 38.6 \times 10^3 \times 278$

$W = 63.8$ kJ

Charging up

3. $P = \frac{V^2}{R}$

$W = Pt$

$W = \frac{V^2}{R}t$

$W = \frac{1090^2}{855} \times 5 \times 60$

$W = 416.9 \times 10^3$ J

$W_{grav} = mgh$

$W_{grav} = 3150 \times 9.81 \times 9.39$

$W_{grav} = 290.2 \times 10^3$ J

efficiency $= \frac{\text{useful output energy}}{\text{total input} \ldots}$

efficien… $\ldots_{grav}$

efficiency $= \frac{290.2 \times 10^3}{416.9 \times 10^3}$

efficiency $= 0.696$ or 69.6 %

4. $P = I^2R$

$W = Pt$

$W = I^2Rt$

$I = \frac{Q}{t}$

$W = \frac{Q^2R}{t}$

$Q = \sqrt{\frac{Wt}{R}}$

$Q = \sqrt{\frac{146 \times 60}{95.4 \times 10^3}}$

$Q = 0.303$ C

Shocking!

5. $I^2R = \frac{P^2R}{V^2}$

$I^2R = \frac{(24.8 \times 10^6)^2 \times 4\ldots}{(30.9 \times 10^{\ldots})\ldots}$

$I^2R = 262.8$ kW

efficiency $= \frac{\text{useful outp…}}{\text{total inpu…}}$

efficiency $= \frac{P - I^2R}{P}$

efficiency $= \frac{30.9 \times 10^{\ldots}}{30.\ldots}$

efficiency $= 0.991$ o…

6. $W_k = \frac{1}{2}mv^2$

$W_k = \frac{1}{2} \times 1035 \times 6\ldots$

$W_k = 2.435 \times 10^6$ J

$I^2R = \frac{P^2R}{V^2}$

$P = \sqrt{\frac{V^2I^2R}{R}}$

$P = \sqrt{\frac{(25.6 \times 10^3)^2 \times 7\ldots}{907}}$

$P = 721.8$ kW

$W = Pt$

$W = 721.8 \times 10^3 \times \ldots$

$W = 3.869 \times 10^6$ J

efficiency $= \frac{\text{useful outp…}}{\text{total inpu…}}$

efficiency $= \frac{W_k}{W}$

efficiency $= \frac{2.435 \times 10^{\ldots}}{3.869 \times 10^{\ldots}}$

efficiency $= 0.629$ o…

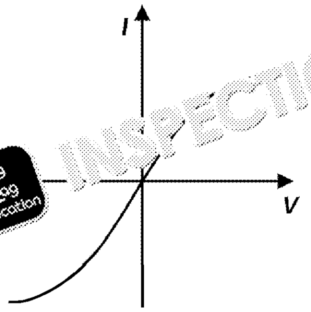
3. I–V CHARACTERISTICS

Bright spark

1. As metal heats up, its resistance increases.

   $R = \frac{V}{I}$ so the gradient of an I–V graph is $\frac{1}{R}$.

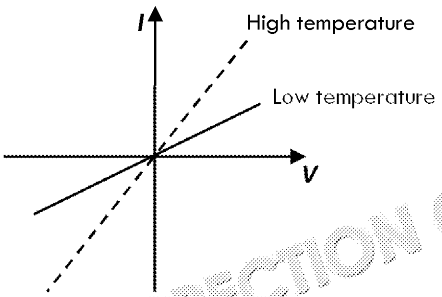
   At higher currents (and temperatures), resistance increases and the gradient of an I–V graph decreases.



2. Current only flows above a threshold potential difference (V_0) or at very high negative potential differences. Resistance decreases with increasing current.

Charging up

3.



A therm[...]sistance decreases with temperature. For an I–V g[...], $gradient \propto \frac{1}{R}$ so a lower resistance means a higher gradient.

4.
- Place ammeter i[...] voltmeter in par[...]
- Take readings o[...]
- Repeat with incr[...]

$R \propto \frac{1}{gradient}$

Gradient at tangen[...]

Gradient = 0.76

$R = 1.3\ \Omega$

Shocking!

6. The component desc[...] This means that the [...] below a threshold p[...] current.

Current /A

Current /

4. RESISTIVITY

Bright spark

1. $R = \frac{\rho L}{A}$

$R = \frac{9.71 \times 10^{-8} \times 37.1 \times 10^{-2}}{(8.43 \times 10^{-3})^2}$

$R = 5.07 \times 10^{-4}\ \Omega$

2. $R = \frac{\rho L}{A}$

$L = \frac{RA}{\rho}$

$L = \frac{92.3 \times 10^{-3} \times 7.}{\ 10}$

$L = 0.9$

Charging up

3. $R = \frac{\rho L}{A}$

$\Delta R = \frac{\rho}{A}(L_2 - L_1)$

$\rho = \frac{\Delta RA}{L_2 - L_1}$

$\rho = \frac{-83.4 \times (1.50 \times 10^{-2})^2}{1.90 - 2.40}$

$\rho = 0.118\ \Omega\,\text{m}$

4. Section 1

$R_1 = \frac{\rho L}{A}$

$R_1 = \frac{2.20 \times 10^{-7} \times 1.60}{\pi \times (8.30 \times 10^{-2})^2 - \pi \times (5.06 \times 10^{-2})^2}$

$R_1 = 2.588 \times 10^{-5}\Omega$

Section 2

$R_2 = \frac{\rho L}{A}$

$R_2 = \frac{\ 0 \times 10^{-7} \times 0.230}{\pi \times (\ \ \times 10^{-2})^2 - \pi \times (6.64 \times 10^{-2})^2}$

$R_2 = 3.782 \times 10^{-6}\ \Omega$

Total

$R = R_1 + R_2$

$R = 2.97 \times 10^{-5}\ \Omega$

Shocking!

5. $R = \frac{\rho L}{A}$

$R_{carbon} = \frac{4.56 \times 10^{-6} \times}{\pi(8.50 \times 10}$

$R_{carbon} = 4.018\ \Omega$

$R_{aluminium} = \frac{2.82 \times 10^{-}}{\pi(6.00 \times}$

$R_{aluminium} = 49.87$ m

$\frac{1}{R_{total}} = \frac{6}{R_{aluminium}} + \frac{1}{R_{car}}$

$\frac{1}{R_{total}} = \frac{6}{49.87 \times 10^{-3}} +$

$\frac{1}{R_{total}} = 120.6$

$R_{total} = 8.295\ \text{m}\Omega$

$P = I^2R$

$P = (320 \times 10^{-3})^2 \times$

$P = 8.49 \times 10^{-4}$ W

6. $A = \pi r^2$

$A_1 = \pi \times (0.661 \times$

$A_1 = 1.373 \times 10^{-4}$

$\rho = \frac{RA}{L}$

$\rho = \frac{31.8 \times 1.373 \times 10^{-4}}{8.51 \times 10^{-2}}$

$\rho = 51.29\ \text{m}\Omega\ \text{m}$

Cross-section of new

$V = L_1A_1$

$V = 8.51 \times 10^{-2} \times$

$V = 1.168 \times 10^{-5}$

$A_2 = \frac{V}{L_2}$

$A_2 = \frac{1.168 \times 10^{-5}}{5.49 \times 10^{-2}}$

$A_2 = 2.128 \times 10^{-4}$

Resistance of new cy

$\rho = \frac{RA}{L}$

$R_2 = \frac{\rho L_2}{A_2}$

$R_2 = \frac{51.29 \times 10^{-3} \times 5.}{2.128 \times 10}$

$\boldsymbol{R_2 = 13.2\ \Omega}$

5. POTENTIAL DIVIDERS

Bright spark

1. $V_{out} = V_{in}\frac{R_2}{R_1 + R_2}$

   $V_{out} = 200 \times \frac{560}{560 + 680}$

   $V_{out} = 90.3$ V

2. $V_{out} = V_{in}\frac{R_2}{R_1 + R_2}$

   $V_{in} = V_{out}\frac{R_1 + R_2}{R_2}$

   $V_{in} = 6$[illegible] $\frac{1.3[illegible] + [illegible] \times 10^3}{[illegible]30 \times 10^3}$

   $V_{in} = 2$[illegible]

Charging up

3. $V_{out} = V_{in}\frac{R_2}{R_1 + R_2}$

   $R = \frac{V_{out}R_1}{V_{in} - V_{out}}$

   $R = \frac{34.6 \times 135}{65 - 34.6}$

   $R = 154\ \Omega$

4. $V_{out} = V_{in}\frac{R_2}{R_1 + R_2}$

   $R_1 = \frac{V_{in}R_2}{V_{out}} - R_2$

   $R = \frac{120 \times 287}{41.6} - 287$

   $R = 541\ \Omega$

Shocking!

5. For $V_{out} = 170$ V

   $V_{out} = V_{in}\frac{R_2}{R_1 + R_2}$

   $R_2 = \frac{V_{out}R_1}{V_{in} - V_{out}}$

   $R_{therm\ T} = \frac{170 \times 78.4}{230 - 170}$

   $R_{therm\ T} = 222.1\ \Omega$

   $R_{therm} \propto \frac{1}{T}$

   $\frac{R_{therm\ 200\ K}}{R_{therm\ T}} = \frac{T}{200}$

   $T = 200 \times \frac{R_{therm\ 200\ K}}{R_{therm\ T}}$

   $T = 200 \times \frac{147}{222.1}$

   $T = 132$ K

6. $V_{out} = V_{in}\frac{R_{LDR}}{R_1 + R_{LDR}}$

   At 30 W m^{-2}

   $R_{LDR} = \frac{(V_{in} - V_{out})R_2}{V_{out}}$

   $R_{LDR} = \frac{(85.0 - 30.0) \times [illegible]}{30.0}$

   $R_{LDR} = 11\ 990\ \Omega$

   For $V_{out} = 54.1$ V

   $R_{LDR} = \frac{(V_{in} - V_{out})R_2}{V_{out}}$

   $R_{LDR} = \frac{(85.0 - 54.1) \times [illegible]}{54.1}$

   $R_{LDR} = 3735$ kΩ

   $R_{LDR} \propto I^3$

   R_{LDR} decreases by [illegible]

   I changes by a facto[illegible]

   $0.6779 \times 30.0 = 2$[illegible]

6. MULTIPLE POWER SOURCES

Bright spark

1. For cells in parallel, $\varepsilon_{total} = \varepsilon_1 = \varepsilon_2 = \varepsilon_3 = 18$ V

   $\varepsilon = IR$

   $I = \frac{\varepsilon}{R}$

   $I = \frac{18}{13}$

   $I = 1.38$ A

   In parallel, $I_{total} = I_1 + I_2$

   $I_{cell} = \frac{1.38}{}$

   $I_{cell} = 0.$

   $I_{cell} = 26$ mA

2. For cells in series, $\varepsilon_{total} = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \ldots$

   $\varepsilon_{total} = 31 + 35 + 42 + 54$

   $\varepsilon_{total} = 162$ V

   $\varepsilon = IR$

   $I = \frac{\varepsilon}{R}$

   $I = \frac{162}{12}$

   $I = 14$ A

Charging up

3. $\varepsilon = 230$ V

   $P = \frac{V^2}{R}$

   $P = \frac{230^2}{84.8}$

   $P = 624$ W

4. $\varepsilon = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \varepsilon_4$

   $\varepsilon = 984 + 2140 + 810 + 1870$

   $\varepsilon = 5804$ V

   $R = R_1 + R_2 = 36.4 \times 10^3 + 23.3 \times 10^3 = 59.6 \times 10^3\ \Omega$

   $P = \frac{V^2}{R} = \frac{2064^2}{59.6 \times 10^3}$

   $P = 565$ W

Shocking!

5. According to Kirchho
   all the resistors is eq
   cell, and the current
   out of a junction.

   $80 = 50 \times I_1 + 100$

   $160 = 75 \times I_2 + 10$

   $(1) \times 2 = (2)$

   $100 \times I_1 + 200 \times ($

   $I_2 = -8 \times I_1$

   Into (1)

   $I_1 = -0.1231$ A

   $I_2 = 0.9846$ A

   $I_3 = I_1 + I_2 = 1.11$ A

6. $\varepsilon = I(R + r)$

   $\varepsilon = 543 + 496 = 1$

   $R = 258\ \Omega$

   $r = 9.61 + r_{parallel}$

   $\frac{1}{r_{parallel}} = \frac{1}{r_1} + \frac{1}{r_2}$

   $r_{parallel} = 6.75\ \Omega$

   $r = 16.36\ \Omega$

   $I = \frac{\varepsilon}{R+r} = 3.787$ A

   $P = I^2(R + r) = 393$

7. CAPACITANCE

Bright spark

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

$\varepsilon_r = \frac{Cd}{A\varepsilon_0}$

$\varepsilon_r = \frac{963 \times 10^{-6} \times 1.98 \times 10^{-3}}{1.44 \times 10^{-4} \times 8.85 \times 10^{-12}}$

$\varepsilon_r = 1.50 \times 10^9$

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

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

$V = \frac{81.\ldots}{185\ldots}$

$V = 440$ V

$W = \frac{1}{2}QV$

$W = \frac{1}{2}\frac{Q^2}{C}$

$W = \frac{1}{2}\frac{(81.4 \times 10^{-3})^2}{185 \times 10^{-6}}$

$W = 17.9$ J

Charging up

3. $W = \frac{1}{2}QV$

$W = \frac{1}{2}CV^2$

$W = \frac{1}{2}C(IR)^2$

$W = \frac{1}{2} \times 249 \times 10^{-6} \times (41.6 \ldots)^2$

$W = 25.1 \times 10^{-3}$ J

4. Electric ... in a uniform field is given by

$V = Ed$

Electric field strength is given by

$E = \frac{Q}{\varepsilon_0 A}$

Capacitance is defined as

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

$Q = E\varepsilon_0 A$

$C = \frac{E\varepsilon_0 A}{Ed}$

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

5. $C = \frac{A\varepsilon_0}{d}$

$C = \frac{134 \times 10^6 \times 8.85 \times 10^{-12}}{40.6 \times 10^3}$

$C = 2.92 \times 10^{-8}$ F

Shocking!

6. $W = \frac{1}{2}QV$

$W = \frac{1}{2}CV^2$

$C = \ldots\varepsilon_r$

$C = \frac{\pi r^2\varepsilon_0\varepsilon_r}{d}$

$C = \frac{\pi \times (7.24 \times 10^{-2})^2 \times 8.85 \times 10\ldots}{14.1 \times 10^{-2}}$

$C = 0.7070$ F

$W = \frac{1}{2} \times 0.7070 \times 85.0^2$

$W = 2550$ J

$W = 2.55$ kJ

7. $V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R_2 - R_1}$

$Q = CV = C \times \frac{1}{4\pi\varepsilon_0}\frac{Q}{R_2 - R_1}$

$C = 4\pi\varepsilon_0(R_2 - R_1)$

$C = 4\pi \times 8.85 \times 10^{-12} \times (\ldots$

$C = 4.07 \times 10^{-12}$ F

8. CAPACITORS IN SERIES AND IN PARALLEL

Bright spark

1. $C_{total} = C_1 + C_2 + C_3 + C_4$

   $C_{total} = 82 \times 10^{-3} + 26 \times 10^{-3} + 31 \times 10^{-3} + 66 \times 10^{-3}$

   $C_{total} = 205$ mF

2. $\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4}$

   $\frac{1}{C_{total}} = \frac{1}{255 \times 10^{-12}} + \frac{1}{310 \times 10^{-12}} + \frac{1}{415 \times 10^{-1}}$ + ...

   $\frac{1}{C_{total}} = 1.410 \times 10^{10}$

   $C_{total} = 7$... pF

   [p = 1

   $C_{total} = 7.09 \times 10^{-11}$ F

Charging up

3. $\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$

   $\frac{1}{C_{total}} = \frac{1}{35.7 \times 10^{-9}} + \frac{1}{18.2 \times 10^{-9}} + \frac{1}{60.3 \times 10^{-9}}$

   $\frac{1}{C_{total}} = 99.54 \times 10^{6}$

   $C_{total} = 10.05$ nF

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

   $Q = CV$

   $Q = 10.05 \times 10^{-9} \times 500 \times 3$

   $Q = 1.51 \times 10^{-5}$ C

4. $C_{total} = C_1 + C_2 + C_3$

   $C_{total} = 550 \times 10^{-6} +$ ... $+ 480 \times 10^{-6}$

   $C_{total} =$ ... μF

   $E = \frac{1}{2}CV$...

   $V = \sqrt{\frac{2E}{C}}$

   $V = \sqrt{\frac{2 \times 6.36}{1640 \times 10^{-6}}}$

   $V = 88.1$ V

Shocking

5. $E = \frac{1}{2}\frac{Q^2}{C_{total}}$

   $C_{total} = \frac{1}{2}\frac{Q^2}{E}$

   $C_{total} = \frac{1}{2}\frac{(382 \times 10^{-}...)}{65.0}$

   $C_{total} = 1.122 \times 1$...

   $\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2 + C}$

   $\frac{1}{C_2 + C} = \frac{1}{C_{total}} - \frac{1}{C_1}$

   $\frac{1}{C_2 + C} = \frac{1}{1.122 \times 10^{-3}}$ ...

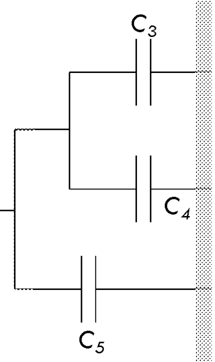
   $\frac{1}{C_2 + C} = 875.7$

   $C_2 + C = 1.142 \times$ ...

   $C = 1.142 \times 10^{-3}$ ...

   $C = 1.06$ mF

6. The circuit describe...



   $C_{total} = C_{top} + C_5$

   $\frac{1}{C_{top}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$ ...

   $C_{top} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3 +}...}$

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

   $\frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3 + C_4}} = C$...

   $\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3 + C_4} =$ ...

   $\frac{1}{C_1} = \frac{1}{C_{total} - C_5} - \frac{1}{C_2}$ ...

   $C_1 = \frac{1}{\frac{1}{C_{total} - C_5} - \frac{1}{C_2}...}$

9. CHARGING AND DISCHARGING CAPACITORS

Bright spark

1. $I = I_0 e^{-\frac{t}{RC}}$

   $I = 72 \times 10^{-3} \times e^{-\frac{60}{38}}$

   $I = 15$ mA

2. $Q_0 = 50$ C

   $T_{1/2} = 25$ s

   $RC = \frac{T_{1/2}}{0.69} = 36$ s

Charging up

3. $V_0 = 37$

   $V_{RC} = 129.5$ V

   $RC = 32.5$ s

   $R = \frac{32.5}{450 \times 10^{-6}}$

   $R = 72.2$ kΩ

4. $V = V_0 e^{-\frac{t}{RC}}$

   $R = -\frac{t}{C}\frac{1}{\ln\frac{V}{V_0}}$

   $R = -\frac{108}{400 \times 10^{-6}} \times \frac{1}{\ln\frac{100}{250}}$

   $R = 295$ kΩ

5. $Q = Q_0(1 - e^{-\frac{t}{RC}})$

   $\frac{Q}{Q_0} = 1 - e^{-\frac{t}{RC}}$

   $e^{-\frac{t}{RC}} = 1 - \frac{Q}{}$

   $-\frac{t}{RC} = \ln(\ \ \frac{}{Q_0})$

   $C = -\frac{t}{R \times \ln(1 - \frac{Q}{Q_0})}$

   $C = -\frac{64.3}{24.5 \times 10^3 \times \ln(1 - 0.819)}$

   $C = 1.54 \times 10^{-3}$ F

Shocking!

6. $\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2}$

   $\frac{1}{R_{total}} = \frac{1}{54.5 \times 10^3} + $

   $R_{total} = 29.22$ kΩ

   $C_{parallel} = 120 \times 10$

   $\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{}{26}$

   $C_{total} = 132.5$ nF

   $Q = Q_0 e^{-\frac{t}{RC}}$

   $t = -RC \ln\left(\frac{Q}{Q_0}\right)$

   $t = -29.22 \times 10^3 \times$

   $t = 0.685$ s

7. a) $Q_0 = 0.085$

   $Q_{RC} = 0.085 \times$

   $RC = 140$ s

   $C = \frac{140}{93.0 \times 10^3}$

   $C = 1.51 \times 10$

   For $W = 1.81$

   $W = \frac{1}{2}\frac{Q^2}{C}$

   $Q = \sqrt{2WC} =$

   $Q = 0.0739$

   This value of Q

   b) $V = V_0(1 - e^{-\frac{t}{RC}}$

   $\frac{V}{V_0} = 1 - e^{-\frac{t}{RC}}$

   $\frac{V}{V_0} = 0.865 =$

Bright spark

1. $\frac{N_s}{N_p} = \frac{V_s}{V_p}$

$V_s = \frac{V_p N_s}{N_p}$

$V_s = \frac{350 \times 140}{240}$

$V_s = 204\ \text{V}$

2. $\text{efficiency} = \frac{I_s V_s}{I_p V_p}$

$\text{efficien[illegible]} \frac{670\ [illegible] \times 450}{[illegible] \times 10^{-3} \times 7.5 \times 10^{3}}$

$\text{efficiency} = 0.31$ or 31 %

Charging up

3. $\text{efficiency} = \frac{I_s V_s}{I_p V_p} = \frac{I_s V_s}{P_p}$

$I_s = \text{efficiency} \times \frac{P_p}{V_s}$

$I_s = 0.942 \times \frac{6.50 \times 10^{3}}{192}$

$I_s = 31.9\ \text{A}$

4. $\frac{N_s}{N_p} = \frac{V_s}{V_p}$

$\text{efficiency} = \frac{I_s V_s}{I_p V_p} = \frac{I_s N_s}{I_p N_p}$

$\text{efficiency} = \frac{37.6 \times 700}{84.3 \times 400}$

$\text{efficiency} = 0.78.1$ or 78.1 %

5. $\text{efficiency} = \frac{I_s V_s}{[illegible]} = [illegible]$

$P = I^2 R$

$\text{efficiency} = \frac{I_s^2 R_s}{P_p}$

$I_s = \sqrt{\text{efficiency} \times \frac{P_p}{R_s}}$

$I_s = \sqrt{0.900 \times \frac{850}{77.3}}$

$I_s = 3.15\ \text{A}$

Shocking!

6. $\text{efficiency} = \frac{I_s V_s}{I_p V_p}$

$\text{efficiency} = \frac{V_s^2}{R_s} \times \frac{1}{I_p V_{[illegible]}}$

$N_s = 1.67 \times N_p = [illegible]$

$\frac{N_s}{N_p} = \frac{V_s}{V_p}$

$V_s = \frac{V_p N_s}{N_p}$

$V_s = \frac{230 \times 300}{180}$

$V_s = 383.3\ \text{V}$

$\text{efficiency} = \frac{383.3^2}{77.8} \times [illegible]$

$\text{efficiency} = 0.241$ [illegible]

7. $P_p = \frac{V_p^2}{R_p}$

$V_p = \sqrt{PR}$

$V_p = \sqrt{985 \times 640}$

$V_p = 794.0\ \text{V}$

$V_p = I_p R_p$

$I_p = \frac{V_p}{R_p}$

$I_p = \frac{794.0}{640}$

$I_p = 1.241\ \text{A}$

Step-down transform[illegible]

$\frac{N_s}{N_p} = \frac{V_s}{V_p}$

$V_s = \frac{V_p N_s}{N_p}$

$V_s = \frac{794.0}{1.76}$

$V_s = 451.1\ \text{V}$

$\text{efficiency} = \frac{I_s V_s}{I_p V_p}$

$I_s = \text{efficiency} \times \frac{I_p V_{[illegible]}}{V_s}$

$I_s = 0.720 \times \frac{1.241 \times [illegible]}{451.[illegible]}$

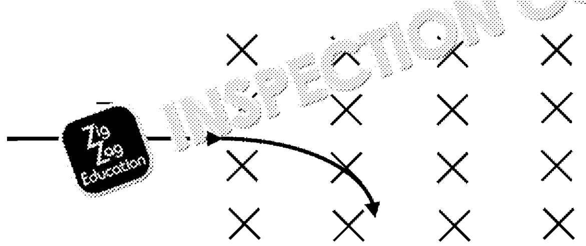
$I_s = 1.57\ \text{A}$

Bright spark

1. Directly between the wires, the two magnetic fields generated by each wire oppose e other, cancelling out.

   Further from the wires, both magnetic fields have the same direction, adding to a larg magnetic field.

   The overall magnetic field is the same shape as for a single wire.

2. 

Charging up

3. The charge carriers (electrons) in the plane's metal frame are moving forwards with th simulating a current.

   Using Fleming's left hand rule (with the magnetic field upwards and positive current b the electrons experience a force to the left, creating a positive current to the right.

   A current is now set up to the right. Using Fleming's left hand rule again for this new cu magnetic field, a force is experienced to the back of the plane – opposing the plane's

4. The balls dropped through the tubes create a magnetic field by the charges moving p other.

   The copper tube has more charge carriers than steel as it is a better conductor, so a st magnetic field is produced.

   Because a stronger magnetic field is produced, a stronger force is felt by the ball pas

   This force opposes the motion of the ball due to Lenz's law – the force opposes the ch This means that the ball in the copper tube moves more slowly than the ball dropped th

Shocking!

5. As an alternating current is passed through the coil of wire, an e.m.f. is induced in the i

   This e.m.f. changes direction with the change in direction of the AC power supply.

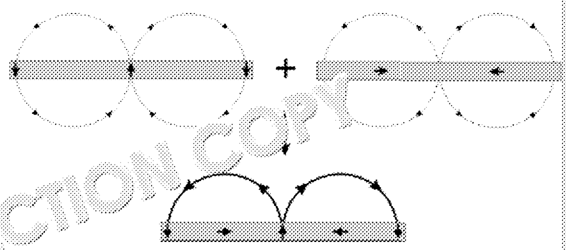
   This induces a current in the brass ring.

   The magnetic field produced by the changing current in the iron core interacts with the upwards.

   As the current or frequency of the AC power supply increases, the brass ring experien

   If the current or frequency of the AC power supply is high enough, the brass ring coul

6. Taking a small section of the array:

   For a downward-facing arrow, the arrows surrounding it add to the magnetic field ab

   For an upward-facing arrow, the arrows surrounding it add to the magnetic field abo

   Where the magnetic fields add, the magnetic field is much stronger. Where the magne is weak, or zero.

   This means that the magnetic field is much stronger above the array than below it.

12. ELECTRICITY GENERATION

Bright spark

1. $N\Phi = BAN\cos\theta$

$N\Phi = 19 \times 10^{-6} \times 3.6 \times 10^{-3} \times 200\cos 0.40$

$N\Phi = 1.26 \times 10^{-5}$ T m²

2. $\varepsilon = -\frac{d(N\Phi)}{dt}$

$\varepsilon = -N\frac{A\Delta B}{\Delta t}$

$\varepsilon = -38 \times \frac{12.6 \times 10^{-4} \times (\ldots \times 10^{-3})}{\ldots}$

$\varepsilon = -6.\ldots$

3. $\varepsilon = BAN\omega\sin\omega t$

$\omega = 170 \times \frac{2\pi}{60} = 17.80$ rad s⁻¹

$\varepsilon = 407 \times 10^{-3} \times 728 \times 10^{-4} \times 120 \times 17.80 \times \sin(17.80 \times 60)$

$\varepsilon = -13.2$ V

Charging up

4. $\varepsilon = -\frac{d(N\Phi)}{dt}$

$N\Phi = BAN\cos\theta$

$\varepsilon = \frac{BAN\Delta\cos\theta}{\Delta t}$

$A = \frac{\varepsilon\Delta t}{BN\Delta\cos\theta}$

$A = \frac{130 \times 10^{-3} \times 2.50}{84 \times 10^{-3} \times 85 \times (\cos 36 - \cos 0)}$

$A = 0.238$ m²

5. Period $= 2\pi$

$T = 0.3\ldots$

$\omega t = 2\pi$

$\omega = \frac{2\pi}{0.32}$

$\omega = 19.6$ rad s⁻¹

6. $\varepsilon = -\frac{d(N\Phi)}{dt}$

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

$\Delta t = \frac{NBA}{\varepsilon}$

$\Delta t = \frac{50 \times 20 \times 10^{-3} \times 300 \times 10^{-6}}{70 \times 10^{-3}}$

$\Delta t = 4.29$ ms

$v = \frac{\Delta x}{\Delta t} = \frac{15 \times 10^{-2}}{4.29 \times 10^{\ldots}}$

$v = 35\ldots$

Shocking!

7. $T = 1.25$ s

$\omega = \frac{2\pi}{T} = \ldots$

$\varepsilon = BAN\omega\ldots$

$BAN\omega = 17\ldots$

$B = \frac{17\,500}{AN\omega}$

$B = \frac{17\ldots}{1.80 \times 3\ldots}$

$B = 0.644$ T

8. $\varepsilon = -\frac{d(N\Phi)}{dt}$

$N\Phi = BAN\ldots$

$\varepsilon = -\frac{BAN\Delta\ldots}{\Delta\ldots}$

$\Delta t = \frac{\Delta\theta}{\omega} = \ldots$

$\Delta t = 0.545\ldots$

$A = -\frac{\varepsilon\Delta\ldots}{BN\Delta\ldots}$

$\Delta\cos\theta = \ldots$

$A = \frac{55.6 \times 1\ldots}{27.3 \times \ldots}$

$A = 0.022\ldots$

13. OSCILLOSCOPES

Bright spark

1. $V_{rms} = \frac{V_0}{\sqrt{2}}$

   $V_0 = \sqrt{2}V_{rms}$

   peak-to-peak voltage $= 2V_0$

   peak-to-peak voltage $= 2 \times \sqrt{2}V_{rms}$

   peak-to-peak voltage $= 2 \times \sqrt{2} \times 110$

   peak-to-peak voltage $= 311$ V

2. **Horizontal**
   Nine divisions

   $\textit{time base setting} = \frac{2 \times \textit{period}}{\textit{number of divisions}}$

   $\textit{time base setting} = \frac{2 \times 12.5 \times 10^{-3}}{9}$

   $\textit{time base setting} = 2.78 \text{ ms div}^{-1}$

   Vertical
   Six divisions

   $\textit{current base setting} = \frac{\textit{peak-to-peak current}}{\textit{number of divisions}} = \frac{2I_0}{\textit{number of divisions}}$

   $\textit{current base setting} = \frac{2 \times 9.4}{6}$

   $\textit{current base setting} = 3.13 \text{ A div}^{-1}$

   Note: These are only the minimum base settings. It's much more likely that higher, more rounded settings would be used in practice, such as 3 ms div^{-1} and 4.0 A div^{-1}.

Charging up

3. **Horizontal**
   One cycle is 3.8 divisions

   $T = \textit{number of divisions} \times \textit{time base setting}$

   $T = 3.8 \times 0.2 \times 10^{-3}$

   $\mathbf{T = 0.76}$ **ms**

   Vertical
   Peak-to-peak voltage is 6.6 divisions

   $V = \textit{number of divisions} \times \textit{voltage base setting}$

   $V_{peak} = 3.3 \times 0.8$

   $V_{peak} = 2.6$ V

Shocking!

4. $I_{rms} = \frac{I_0}{\sqrt{2}}$

   $I_{rms} = \frac{38.4}{\sqrt{2}}$

   $I_{rms} = 27.15$ A

   number of divisions =

   number of divisions =

   number of divisions =

   percentage uncertainty

   percentage uncertainty

   percentage uncertainty

   absolute uncertainty I_{rms}

   absolute uncertainty I_{rms}

   absolute uncertainty I_{rms}

5. 4.9 divisions horizontal
   6.3 divisions vertically

   $T = \textit{number of divisions}$

   $T = 4.9 \times 1.5 \times 10^{-3}$

   $T = 7.35$ ms

   percentage uncertainty

   percentage uncertainty

   percentage uncertainty

   $f = \frac{1}{T}$

   $f = \frac{1}{7.35 \times 10^{-3}}$

   $\mathbf{f = 136}$ **Hz**

   absolute uncertainty f =

   absolute uncertainty f =

   absolute uncertainty f =

   $V_0 = \frac{1}{2}V_{\textit{peak to peak}}$

   $V_0 = \textit{number of divisi}$

   $V_0 = \frac{1}{2} \times 6.3 \times 2.5$

   $\mathbf{V_0 = 7.88}$ **V**

   percentage uncertainty

   percentage uncertainty

   percentage uncertainty

   absolute uncertainty V_0

   absolute uncertainty V_0

   absolute uncertainty V_0

EXAM STYLE QUESTIONS

1 a

$R_{total} = R_{series} + R_{parallel}$

$\frac{1}{R_{parallel}} = \frac{1}{R_1} + \frac{1}{R_2}$

$\frac{1}{R_{parallel}} = \frac{1}{22 \times 10^3} + \frac{1}{24 \times 10^3}$

$\frac{1}{R_{parallel}} = 8.71 \times 10^{-5}$ ✓

$R_{parallel} = 11500\ \Omega$ ✓

$R_{total} = 1150$[illegible] $\times$ [illegible] ✓

[illegible] $28.$[illegible] $\times 10^3\ \Omega$ ✓

b

$\varepsilon_{total} = \varepsilon_1 + \varepsilon_2$

$\varepsilon_{total} = 21 + 19$

$\varepsilon_{total} = 40$ V ✓

$\varepsilon = I(R + r)$

$r_{total} = r_1 + r_2$

$r_{total} = 0.68 + 0.34$

$r_{total} = 1.02\ \Omega$ ✓

$I = \frac{\varepsilon}{R + r}$

$I = \frac{40}{28.5 \times 10^3 + 1.02}$ ✓

$I = 1.4 \times 10^{-3}$ A ✓

c

$P = I^2(R + r)$

$P = \left(1.4 \times 10^{-3}\right)^2 \times (28$[illegible]$+$[illegible]$2)$ ✓

$P = 0.056$ W [illegible]

2 a

[illegible]

$\rho = \frac{1.1 \times 10^{-4} \times \left(8.3 \times 10^{-2}\right)^2}{12 \times 10^{-2}}$ ✓

$\rho = 6.31 \times 10^{-6}\ \Omega$ m ✓

b

$V = A_1 L_1 = 12 \times 10^{-2} \times \left(8.3 \times 10^{-2}\right)^2$

$V = 8.27 \times 10^{-4}$ m³ ✓

$A_2 = \frac{V}{L_2} = \frac{8.27 \times 10^{-4}}{1.3}$

$A_2 = 6.36 \times 10^{-4}$ m² ✓

$R_2 = \frac{\rho L_2}{A_2}$

$R_2 = \frac{6.31 \times 10^{-6} \times 1.3}{6.36 \times 10^{-4}}$ ✓

$R_2 = 1.29 \times 10^{-2}\ \Omega$ ✓

c

$P_{dissipated} = I^2 R$

[illegible]

$P_{dissipated} = \frac{P^2 R}{V^2}$ ✓

$P_{dissipated} = \frac{45^2 \times 1.29 \times 10^{-2}}{92^2}$ ✓

$P_{dissipated} = 3.1 \times 10^{-3}$ W ✓

3	**a**	$C = \frac{A\varepsilon_r\varepsilon_0}{d}$ $\varepsilon_r = \frac{dC}{A\varepsilon_0}$ ✓ $\varepsilon_r = \frac{6.5\times10^{-3}\times850\times10^{-6}}{\pi\times(4.1\times10^{-3})^2\times8.85\times10^{-12}}$ ✓ $\varepsilon_r = 1.18\times10^{10}$ ✓
	b	$C_{parallel} = C_1 + C_2$ $C_{parallel} = 2\times850\times10^{-6}$ $C_{parallel} = 1.70\times10^{-3}$ F [illegible] $\frac{1}{C_{total}} = \frac{1}{C_{series}}$ [illegible] [illegible] $\frac{1}{[illegible]50\times10^{-6}} + \frac{1}{1.70\times10^{-3}}$ ✓ $\frac{1}{C_{total}} = 1770$ $C_{total} = 5.65\times10^{-4}$ F ✓
	c	$\frac{V_0}{2} = \frac{280}{2} = 140$ V ✓ $T_{1/2} = 105$ s ✓ $T_{1/2} = 0.69RC$ $R = \frac{T_{1/2}}{0.69\times C}$ $R = \frac{105}{0.69\times5.65\times10^{-4}}$ ✓ $R = 270\times10^3\ \Omega$ ✓
4	**a**	$\omega T = 2\pi$ $\omega = \frac{2\pi}{T}$ ✓ $\omega = \frac{2\pi}{1.3}$ ✓ $\omega = 4.83$ rad s^{-1} ✓
	b	$\varepsilon = BAN\omega \sin \omega t$ $B = \frac{\varepsilon}{AN\omega}$ ✓ [illegible] $\frac{[illegible]}{[illegible]\times320\times4.83}$ ✓ B [illegible]5 T ✓
	c	efficiency $= \frac{I_sV_s}{I_pV_p}$ efficiency $= \frac{I_sN_s}{I_pN_p}$ ✓ $I_s =$ efficiency $\times \frac{I_pN_p}{N_s}$ ✓ $I_s = 0.83\times\frac{210\times10^{-3}\times75}{110}$ ✓ $I_s = 0.12$ A ✓
	d	$Horizontal\ divisions = \frac{T}{number\ of\ divisions}$ $Horizontal\ divisions = \frac{1.3}{12}$ $Horizontal\ divisions = 0.1$ s div^{-1} ✓ $\frac{V_s}{V_p} = \frac{N_s}{N_p}$ $V_s = V_p\times\frac{N_s}{N_p}$ $V_s = 135\times\frac{110}{7[illegible]}$ [illegible]8 V[illegible]divisions $= \frac{V}{number\ of\ divisions}$ Vertical divisions $= \frac{198}{8}$ Vertical divisions $= 25$ s div^{-1} ✓