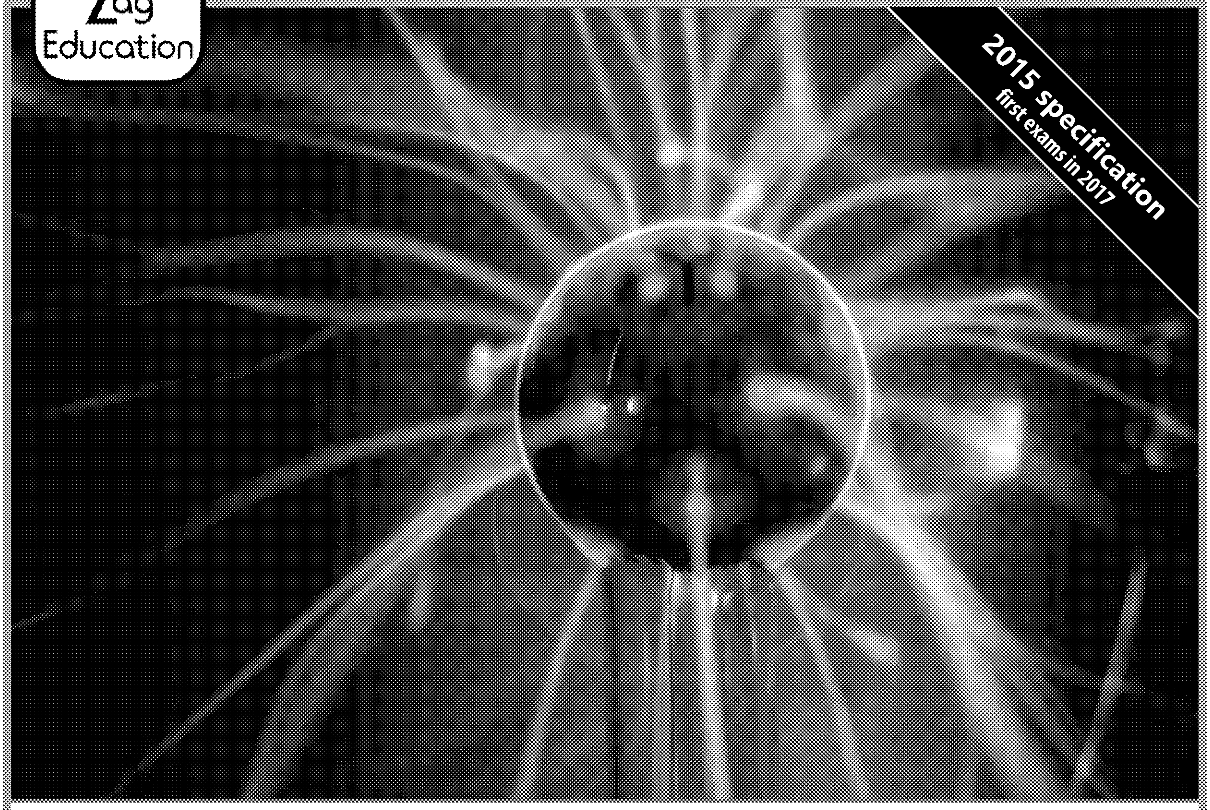
Physics A Level | OCR A | H556



Electricity and Magnetism Technical Topics Worksheets

for A Level OCR A Physics

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POD 8100

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 course, specifically including content from **Module 4 – Electrons, waves and photons** and **Module 6 – Particles and medical physics**.

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 OCR A 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
- 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 Electrics topics. This is followed by 12 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.

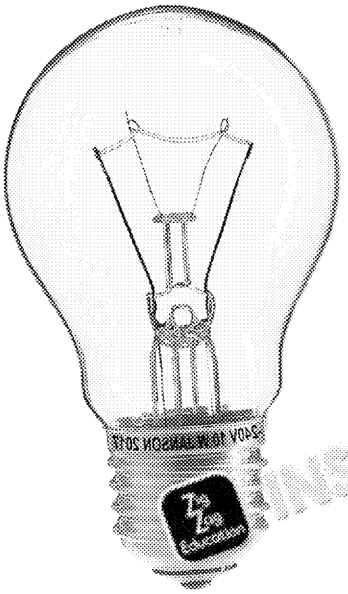
T Brown, December 2017

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	I–V characteristics	13	• Drawing and interpreting I–V graphs for a range of components	4.2.3
2	Resistivity	16	• Performing calculations using resistivity, including for non-regular objects	4.2.4
3	Power	19	• Performing calculations involving power and energy usage in circuits	4.2.5
4	Resistors in series and parallel	21	• Performing calculations for combinations of resistors in series and parallel	4.3.1
5	Multiple power sources	23	• Analysing circuits with more than one power source • Performing calculations using circuits with more than one power source	4.3.1
6	Potential dividers	26	• Interpreting and designing potential divider circuits using thermistors and LDRs • Performing calculations to find resistances and potential differences in potential divider circuits	4.3.3
7	Dielectrics	29	• Understanding how capacitors use potentials to store charge • Perform calculations involving capacitance and dielectrics	6.2.3
8	Capacitors in series and parallel	32	• Perform calculations involving multiple capacitors in series and parallel	6.1.1
9	Charging and discharging capacitors	34	• Analysing capacitor charge and discharge graphs and using them in calculations	6.1.3
10	Transformers	38	• Performing calculations using transformers	6.3.3
11	Electricity generation	41	• Performing calculations relating to electricity generation	6.3.3
12	Electromagnetic phenomena	45	• Analysing and interpreting situations involving Lenz's and Faraday's laws of electromagnetic induction	6.3.3

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 Aless scientists to generate electricity, while Michael F Edison's filament bulb harnessed electricity for a from scientists such as Galileo Ferraris, Ányos Je Westinghouse allowed electricity to be reliably over long distances for use in industries, public

Today, the applications of electricity and magn cables which transfer power across countries to h 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 different forms and applications. Electricity and magnetism topics include a tricky to use, and require a strong understanding of the principles involved. on electricity and magnetism, you'll have to be able to rearrange equation 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 a
- 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 feeling confident, you should go slowly and spend some time buil
knowledge and understanding before tackling these topics with the A Lev

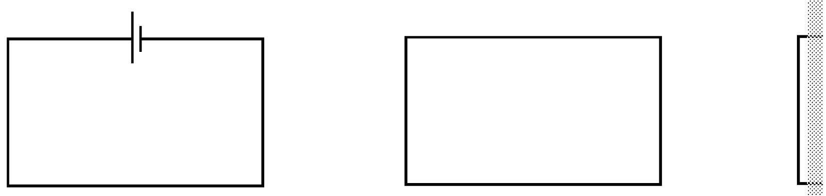
THE BASICS OF ELECTRICITY

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 dif**
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 f
Circuit C has a power source but is **not a closed loop** – there is a gap in the c

- **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 w

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

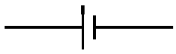
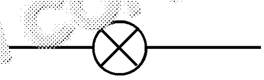
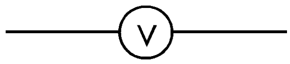
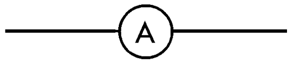
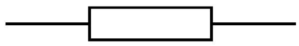
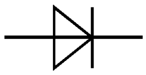
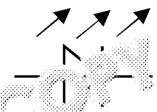
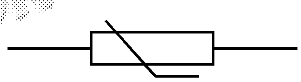
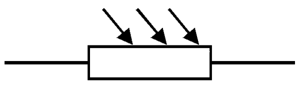
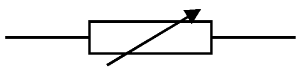
Potential difference or **voltage, *V*,** is the energy transferred to a charge ca
Potential difference is the driving force behind the current in a circuit.

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

COMPONENTS

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

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

Component	Symbol	
Cell		P
Bulb		
…meter		M
Ammeter		
Ohmmeter		
Resistor		
Switch		Cl 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.

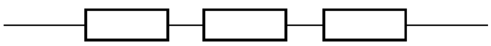
The relationship between current, potential difference and resistance is

$$V = IR$$

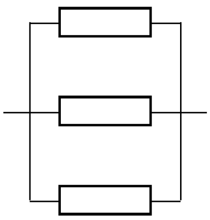
So a component with a resistance of 3 Ω and a current of 4 A flowing throu
will have a potential difference of $V = 3 \times 4 = 12$ V across it.

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 p
between the components.

For a series circuit, the total resistance is given by

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

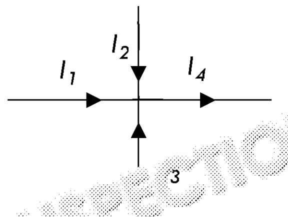
When resistors are placed in parallel, the total resistance of the arrangeme
the current has more paths to flow through, so each path needs to carry less
difference needed to drive the same current. Potential difference is the sa
parallel circuit, while current is split across each branch.

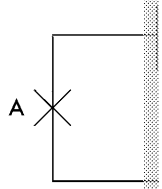
KIRCHHOFF'S LAWS

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.

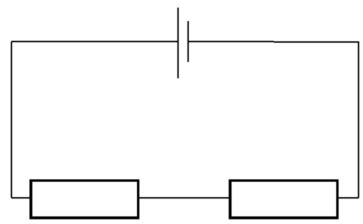




The current into a point must equal the current out of the point.
In the circuit on the left, $I_4 = I_1 + I_2 + I_3$.
In the circuit on the right, the current at point A = the current at point B.

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.



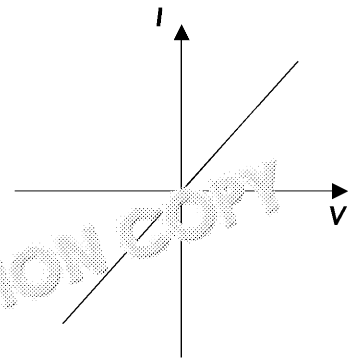
In this circuit, the potential difference supplied by the cell exactly equals th across both resistors.

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

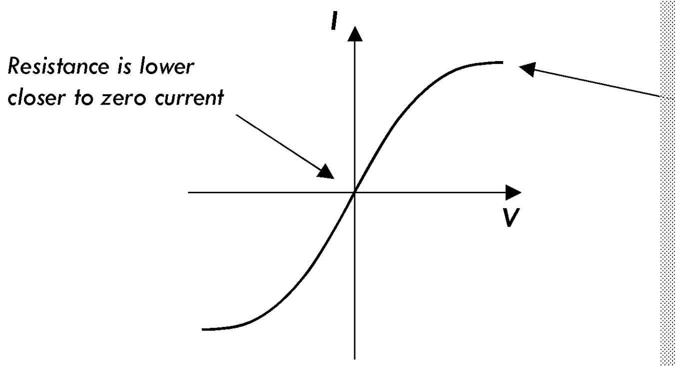
I-V CHARACTERISTICS

Components respond to increasing current and potential difference in differ

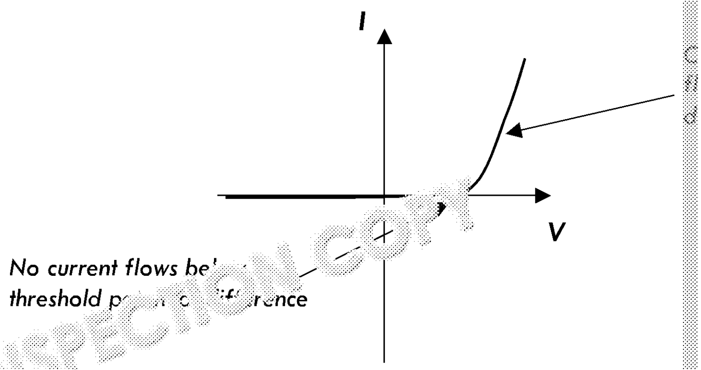
An **ohmic conductor** is one that has a **linear** relationship between potential d
resistance of an ohmic conductor is **constant**, no matter the current through it o



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



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.

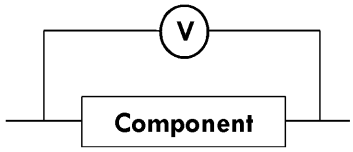
The resistance of a thermistor **decreases with increasing temperature**. This
measure temperature, or build a circuit that responds to changes in tempera

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

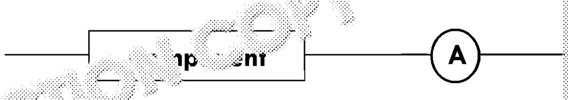
The potential difference across a component or section of a circuit can be m

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



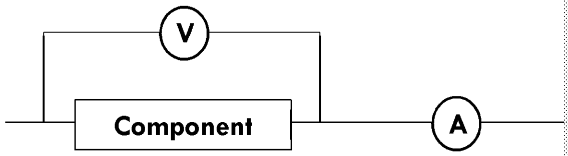
The current through a component can be measured using an **ammeter**.

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 transf of energy can be into many different forms – for example, as light, heat, o 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 will have transferred $E = 32 \times 60 = 19$

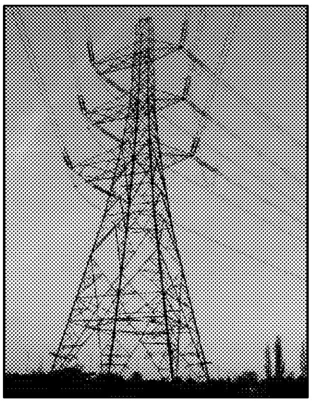
Not all power transferred by a component is useful. Some energy will be transf considered wasted energy. For example, a bulb will produce light but also p and sound. All components with a current running through them will produce

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

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

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 device
an external source of power.

Electrical energy production is one of the largest i
electricity is transmitted over the **National Grid**. T
wires and transformers which transfer electricity fr
businesses.

Electricity is transmitted as an **alternating curren**
direction of the current change direction repeat

Alternating current i ... ea to **direct current**
This means ... e ...rent supplied is a single, c

The electricity supplied to ho... ...K is AC, with a **potential difference of 2**

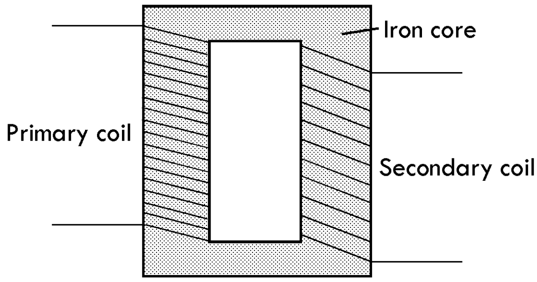
Transfor

When trans... 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 **transfor**

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 dif

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

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

THE GENERATOR EFFECT

When a co...r 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 ______________.

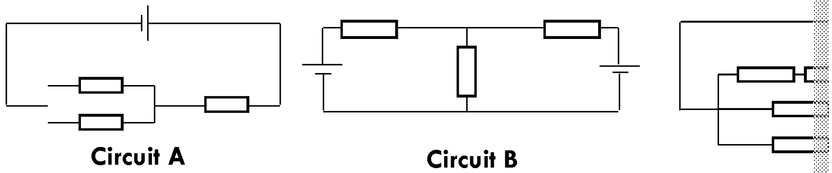
   ______________ *is the energy transferred to a charge.*

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

   through it.

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

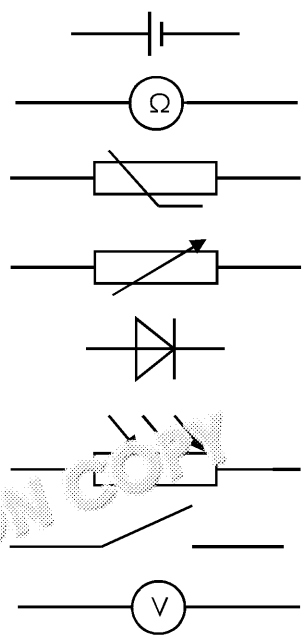
3. For each of the circuits below, state whether or not a current will flow, a



Circuit A **Circuit B**

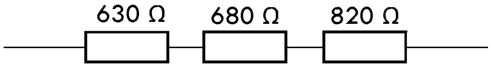
4. Match each component with its symbol and use.

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



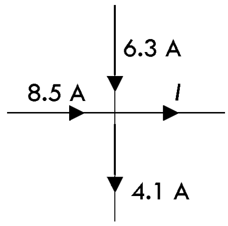
5. 850 mA flows through a resistor with a potential difference of 52 V ac Calculate the resistance of the resistor.

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

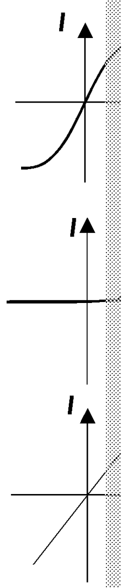
____________________.

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 [illegible] of the generator effect.

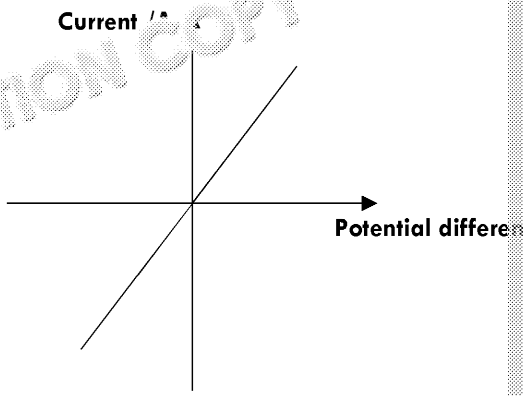
1. I–V CHARACTERIS

4.2.3: RESISTANCE

BACKGROUND

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

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

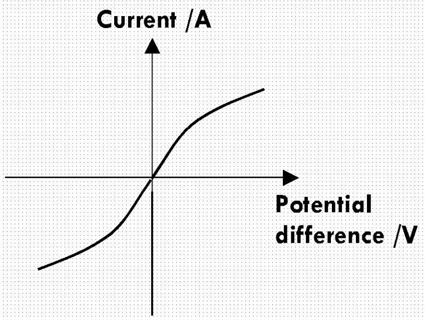


Resistance is given by $R = \frac{V}{I}$, and for an I–V graph gradient $= \frac{I}{V}$, so $R =$

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

Example 1

The I–V graph of a filament lamp is shown below.



Describe the resistance of a filam... lamp at different current...

EXTENS

Explain th... perties of a filament lamp in terms of charge carriers.

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 ... heats up, atoms vibr
...ectrons 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 very high negative potential differences.

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

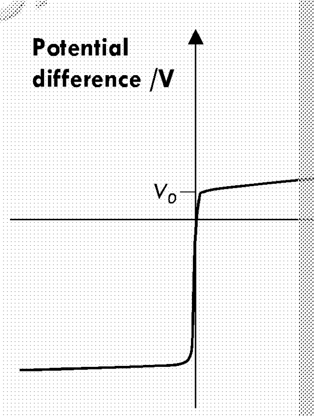
A V–I graph has potential difference, V
and current, I, on the x-axis.

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

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

At high negative potential differences,

This means th... V–I graph for a se

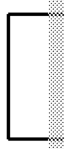


QUESTIONS

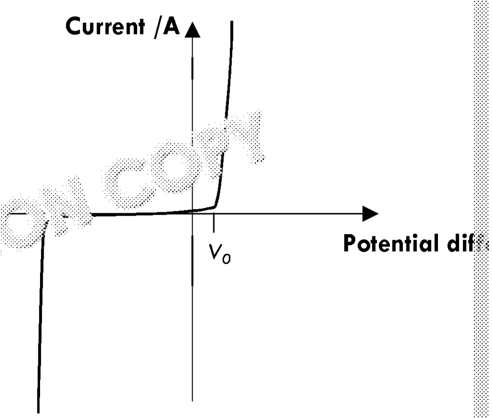
Bright spark

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.



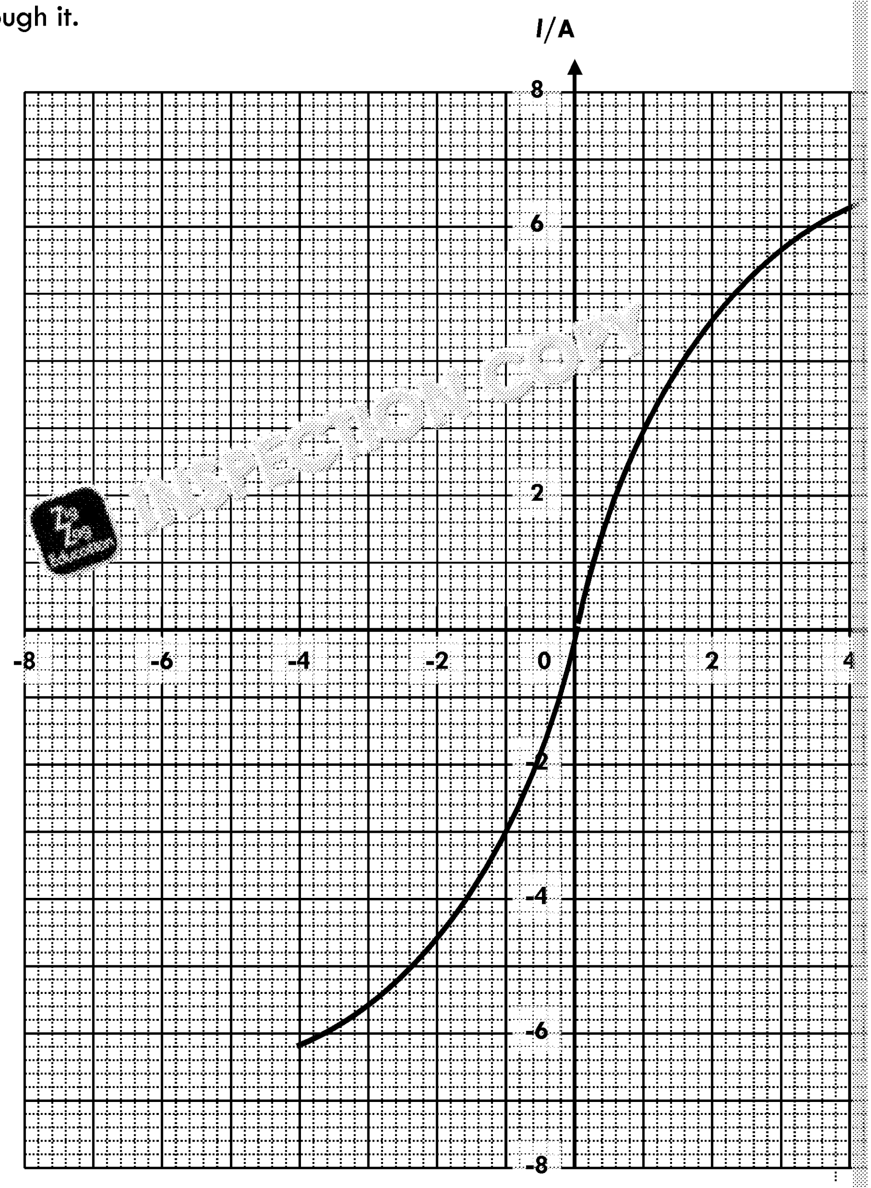
Charging up

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 charac

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



Shocking!

6. A component consists of a negative region with an excess of electrons a 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, and accordingly.

   At high currents, the memristor always has the same resistance. At low 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.

2. RESISTIVITY

4.2.4: RESISTIVITY

BACKGROUND

The resistance of an object – how well it can stop or 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 it.
- **Dimensions:** A longer wire will have a hi ne sistance because there current. A narrower wire will h her resistance as well because current to pass through.

The resista a ject 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

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

$$\rho = \frac{20.7\times10^{-3} \times 1.257\times10^{-3}}{1.5}$$

$\rho =$ Ω m

EXTENSION:

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

The new length of the copper wire is 155

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

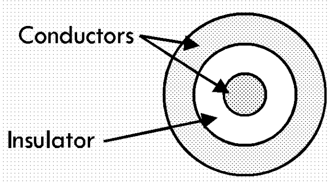
$$R = \frac{1.68\times10^{-8} \times 1930}{1.257\times10^{-3}}$$

$\boldsymbol{R = 25.7}$ **mΩ**

EXA
Rem
use S
In thi
conv

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 inn

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

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

And the resistance of the ou

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

$$R_{outer} = 6.069\times10^{-4}\ \Omega$$

The wire and ring are in pa resistance is given by

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

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

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

$$\mathbf{R_{total} = 3.02\times10^{-4}\ \Omega}$$

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 9.71×10^{-8} Ω m.

   Calculate the resistance of the iron bar.

2. A wire has a resistivity of 6.72×10^{-7} Ω 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 i… 2.40 m to 1.90 m.

   The resist…ce … ire decreases by 83.4 Ω.

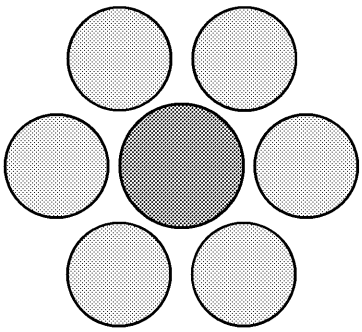
   Calcul… resistivity of the wire.

4. The resistivity of lead is 2.20×10^{-7} Ω 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 4.56×10^{-6} Ω m, wires, with a resistivity of 2.82×10^{-8} Ω 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 ca… carrying 320 mA

6. A lump of conductive putty is mould… to … cylinder. The length of the the radius is 0.662 cm.

   The resist…ce … utty cylinder is 31.8 Ω.

   The sa…ume of putty is remoulded into a cylinder with a length of

   Calculate the resistance of the new cylinder.

3. POWER

4.2.5: POWER

BACKGROUND

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

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 transferre want the total energy.

Power is defined as the energy transferred per uni so

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

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

Substituting in values gives

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

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

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 char

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

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 by It's important not to get these two mixed up.

The power dissipated by the cables is given b

$P_{dissipated} = I^2R$

Substituting $I = \frac{P}{V}$ gives

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

Substituting in values giv

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

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

$\boldsymbol{I^2R = 34}$ **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 bulb.

2. A resistor has a resistance of 38.6 kΩ and a current of 77.1 mA running Calculate the energy dissipated by the resistor.

Charging up

3. A crane is 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. T resistance of 95.4 kΩ.

   Calculate the charge that passes through th ea ng element.

Shocking!

5. While being used that power magnets in a particle accelera MW of ve a potential difference of 30.9 MV across the

   The ca ve a resistance of 408 kΩ.

   Calculate the efficiency of the cables which supply the magnets used in

6. A magnetic propulsion system consists of a track which accelerates 103 68.6 m s^{-1} in 5.36 s.

   The tracks dissipate a power of 721 kW, and have a resistance of 907 of 25.6 kV across them.

   Calculate the efficiency of the magnetic propulsion system.

4. RESISTORS IN SERIES AND I

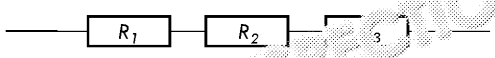
4.3.1: SERIES AND PARALLEL CIRCUITS

BACKGROUND

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

	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

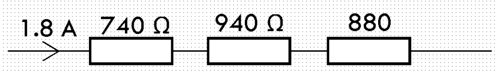


$R_{total} = R_1 + R_2 + R_3 + \ldots$

The total resistance of co 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

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

$R_{total} = 2560\ \Omega$

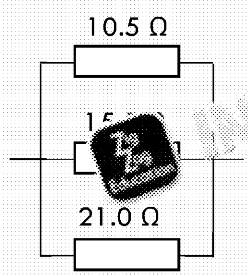
Use $V = IR$
and substitute in values to give

$V = 1.8 \times 2560$

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

Another method would be to indiv 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

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

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

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

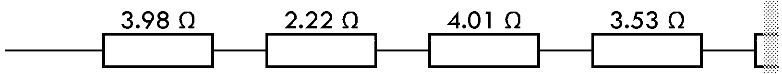
You might find it easier to first find

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

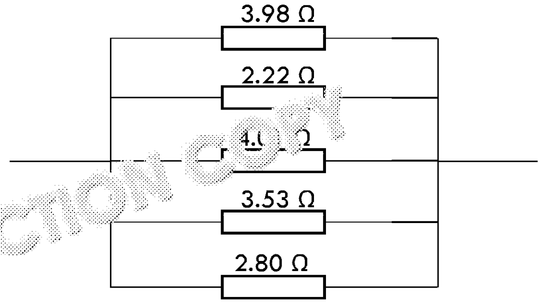
QUESTIONS

Bright spark

1. Calculate the combined resistance of the components below.

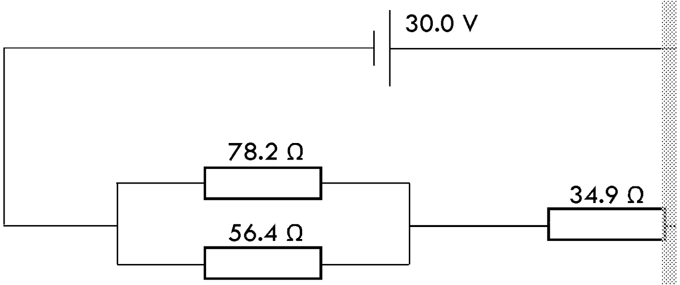


2. Calculate the combined resistance of the components below.

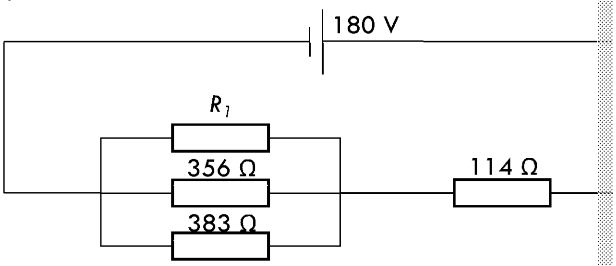


Charging up

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

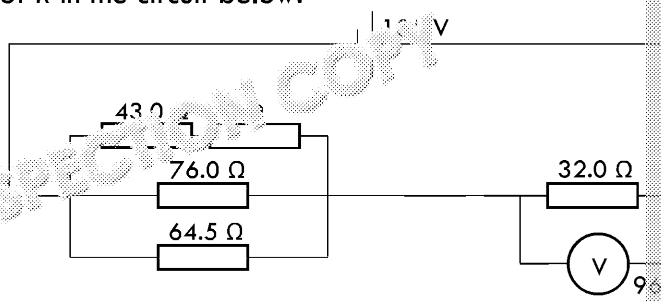


4. Calculate the value of R_1 in the circuit below.



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 suppl
26 V, an ammeter, and the two resistors, R_1 *and* R_2, in series. The amm

Calculate R_1 *and* R_2.

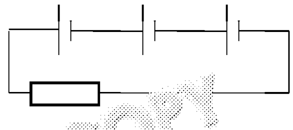
5. MULTIPLE POWER S

4.3.1: SERIES AND PARALLEL CIRCUITS

BACKGROUND

Power sources can be placed in series or in parallel.

Series

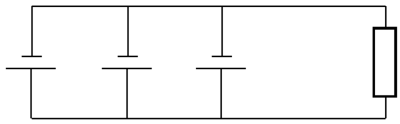


For a series circuit, the e.m.f. delivered to the circuit is the sum of the e.m.f.s

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

For power sources in series, the current can actually decrease – adding cell 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 comp putting the cells in parallel decreases the combined internal resistance, so th decreases.

Internal resistance

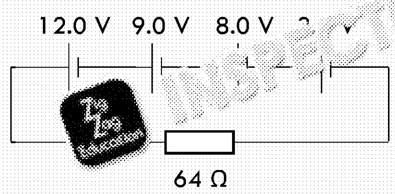
For a cell with a non-negligible internal resistance, the e.m.f. of the cell is gi

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

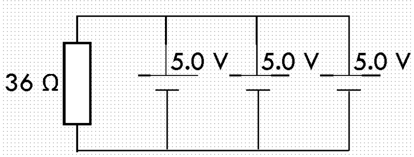
Example 1

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

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

$\varepsilon_{total} = 32\ \text{V}$

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

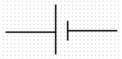
$V = IR \rightarrow I = \frac{V}{R}$

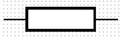
Substituting gives

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

$\boldsymbol{I = 0.50\ A}$

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 [illegible] ig ble internal resista

$\varepsilon = I(R$ [illegible]

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 curre arrangement, so this dissipates less powe placed in parallel.

QUESTIONS

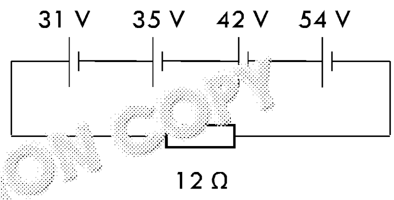
Bright spark

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

   These cells are connected to a 13 Ω resistor.

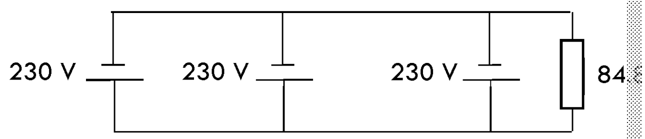
   Calculate the current through the resistor and a single cell.

2. Calculate the current in the circuit below.

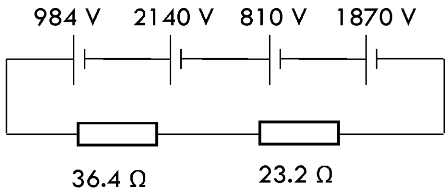


Charging up

3. Calculate the power dissipated by the circuit below.

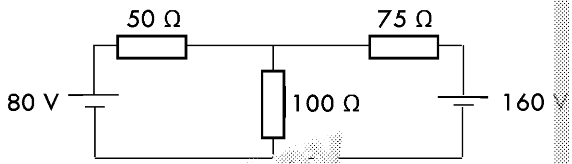


4. Calculate the power dissipated by the circuit below.

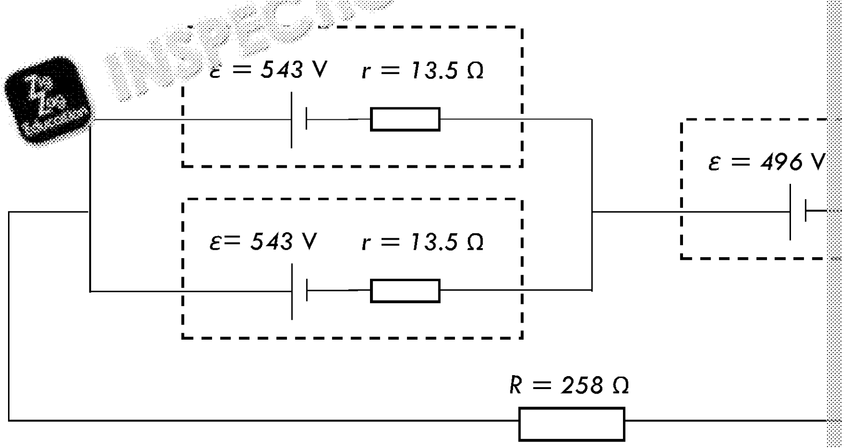


Shocking!

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



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



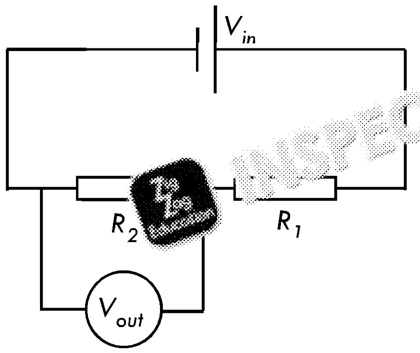
6. POTENTIAL DIVID

4.3.3: POTENTIAL DIVIDERS

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.

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

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

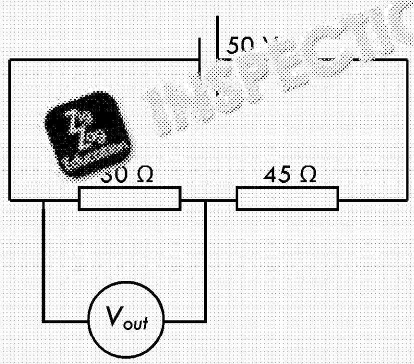
$V = IR$ so

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

These equations are **not** given in the data booklet, so make sure you learn t

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

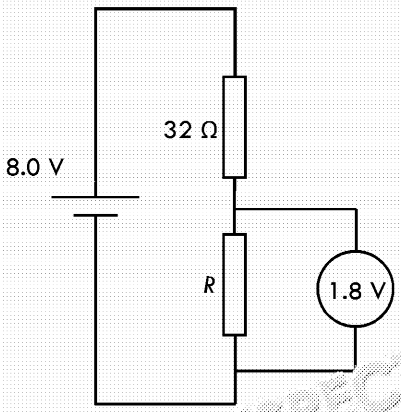
$V_{out} = 50 \times \frac{30}{30 + 45}$

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

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 and

We want $R = R_2$, so we'll need to r

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

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

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

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

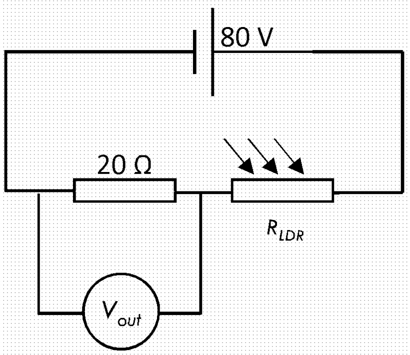
and substitute values in

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

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

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 for R_1

$V_{out}(R_1 + R_2) = V_{in}R_2$ [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 Ω

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

so

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

Rearrange for $R_{LDR\ 90}$

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

Substitute values in

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

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

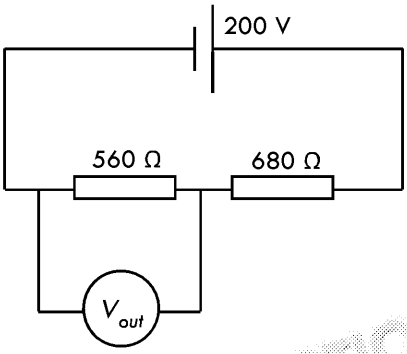
EXAM TIP

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

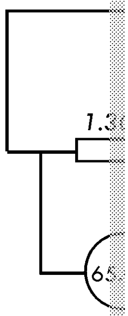
QUESTIONS

Bright spark

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

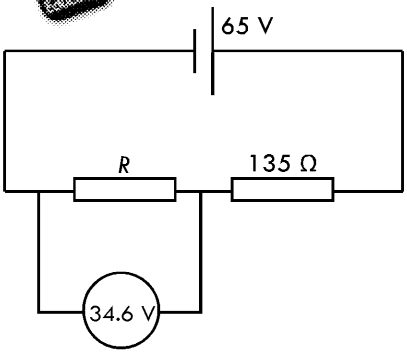


2. Calculate V_{in}

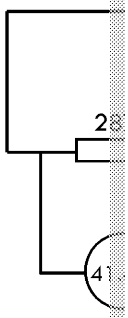


Charging up

3. Calcul value of R in the circuit below.



4. Calculate R in

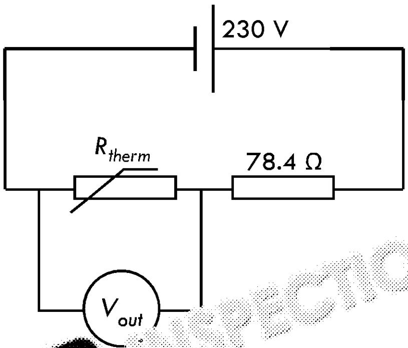


Shocking!

5. At 200 K, R_{therm} is 147 Ω.

   The response of the thermistor is $R_{therm} \propto \frac{1}{T}$.

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

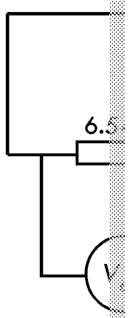


6. At 30.0 W m

   The response

   Calculate the

   $V_{out} = 54.1$ V.



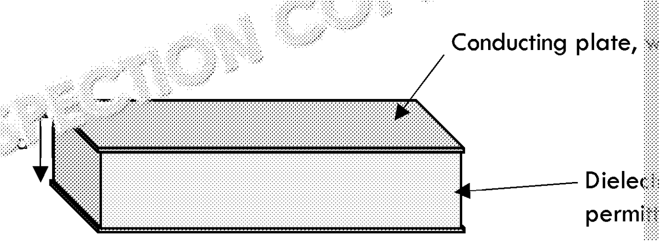
7. DIELECTRICS

6.2.3: UNIFORM ELECTRIC FIELD

BACKGROUND

A capacitor is a component which stores charge, and dissipates that charge over time.

A capacitor consists of a dielectric (an insulating material) between two conducting plates.



The capacitance of a capacitor is given by

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

For a parallel plate capacitor

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

The energy stored by a capacitor is

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

$C =$ c
$Q =$ c
$V =$ p
$A =$ c
$\varepsilon_0 =$ p
$\varepsilon_r =$ r
$d =$ d
$E =$ e

Example 1 A capacitor has a capacitance of 840 μF and stores a charge of 32 mC. Calculate the energy stored by the capacitor.	Use $E = \frac{1}{2}QV$ but we need it in a form with charge and capacita difference. $V = \frac{Q}{C}$ so $E = \frac{1}{2}Q \times \frac{Q}{C} = \frac{1}{2}\frac{Q^2}{C}$ Substituting in values gives $E = \frac{1}{2} \times \frac{(32 \times 10^{-3})^2}{840 \times 10^{-6}}$ $\boldsymbol{E = 0.61}$ **J**

Example 2
A conductive sheet has an area of 78 cm2. Placed 6.0 cm above the sheet is another conductive sheet with an area of 32 cm2.

A dielectric is placed between the two sheets, such that the capacitance of the set-up is 12 mF.

Calculate the relative permittivity of the dielectric.

For the equation $C = \frac{A\varepsilon_0\varepsilon_r}{d}$, A ref… area of the two plates.

This means that for this arrangem… the size of the smaller sheet, 32 …

Rearrange for ε_r

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

Substitute in values

$\varepsilon_r = \frac{12 \times 6.0 \times 10^{-2}}{32 \times 10^{-4} \times 8.85 \times 10^{-12}}$

$\boldsymbol{\varepsilon_r = 2.54 \times 10^{10}}$

EXAM TIP
The potential of an electric field at a distance r …

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

This only applies in a vacuum and to conductors…

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

This is the general form of the equation. For a v…
This equation lets us find the potential in a capa…

Example 3
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

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

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

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

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

EXAM TIP
r is used fo…
electric fiel…
when talkin…
Make sure …

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 in the capacitor.

2. A capacitor has a capacitance of 185 µF and stores a charge of 81.4

   Calculate the potential difference across the capacitor and the energy

Charging up

3. A capacitor has a capacitance of 24[illegible]F. The capacitor has a resistan 41.6 mA flowing through it

   Calculate the energy stored in the capacitor in J.

4. A capacitor consists of two circular parallel plates with a radius of 7.2 apart, and the dielectric constant between them has a relative permitti

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

Shocking!

5. A storm cloud covers an area of 134 km^2.

   A lightning strike represents a potential difference of 6.14×10^8 V and

   Calculate the height of the storm cloud above the ground.

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

   R_1 = radius of internal sphere = 2.43 cm

   R_2 = radius of external sphere = 6.09 cm

   $\varepsilon_r = 3.40 \times 10^{10}$

   Calculate the capacitance of the spherical capacitor.

8. CAPACITORS IN SERIES AND

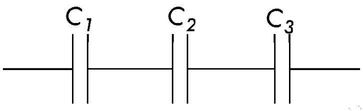
6.1.1: CAPACITORS

KEY SKILLS
Perform calcula
capacitors in se

BACKGROUND

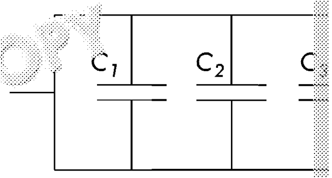
Capacitors are often only available in specific values of capacitance, but a or lower capacitance than those available. Like resistors, capacitors can be arrangements, allowing a wide range of capacitance from few capacitors w

For capacitors in series



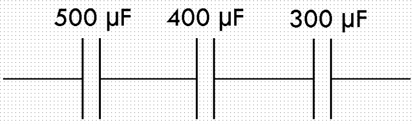
$$\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

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

$$\frac{1}{C_{total}} = \frac{1}{500 \times 10^{-6}} + \frac{1}{400 \times 10^{-6}}$$

$$\frac{1}{C_{total}} = 7833$$

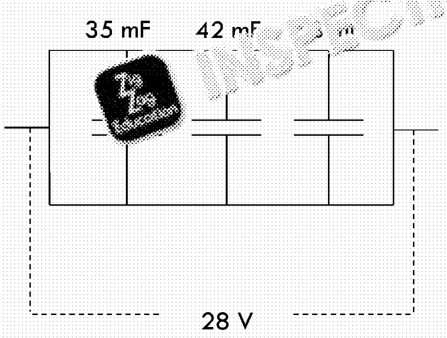
Rearranging for C_{total} gives

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

$C_{total} = 35 \times 10^{-3} + 42 \times 10^{-3} + 6$

$C_{total} = 145$ mF

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

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

Substituting in values gives

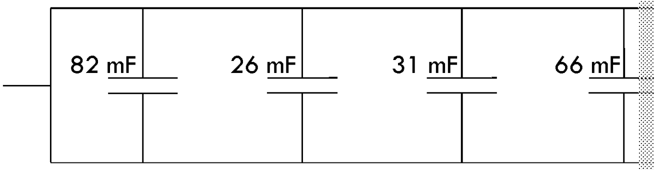
$$E = \frac{1}{2} \times 145 \times 10^{-3} \times 28^2$$

$\mathbf{E = 57\ J}$

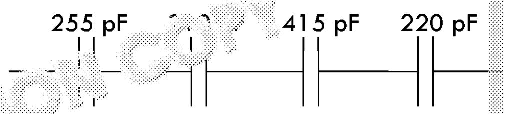
QUESTIONS

Bright spark

1. Calculate the combined capacitance of the arrangement of capacitors

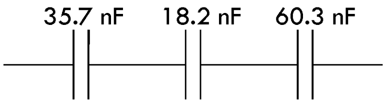


2. Calculate the combined capacitance in F of the arrangement of capaci

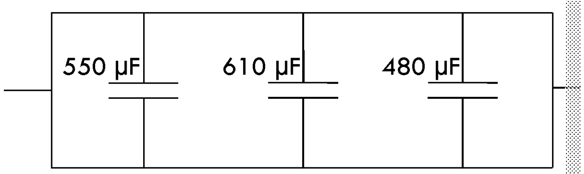


Charging up

3. The cc rs below can have a maximum potential difference of 500
Calcul e maximum total charge stored in the capacitors.



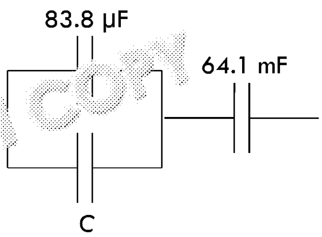
4. Calculate the potential difference across all of the capacitors below wh
whole arrangement is 6.36 J.



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 to acitance 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
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

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

9. CHARGING AND DISCHARGING CAPACITORS

6.1.3: CHARGING AND DISCHARGING CAPACITORS

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.

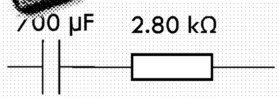
RC is known as the time constant of the capacitor, and is the time it takes for the capacitor to discharge to $e^{-1} = 0.37$ of its initial charge.

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 ca 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*

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

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

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

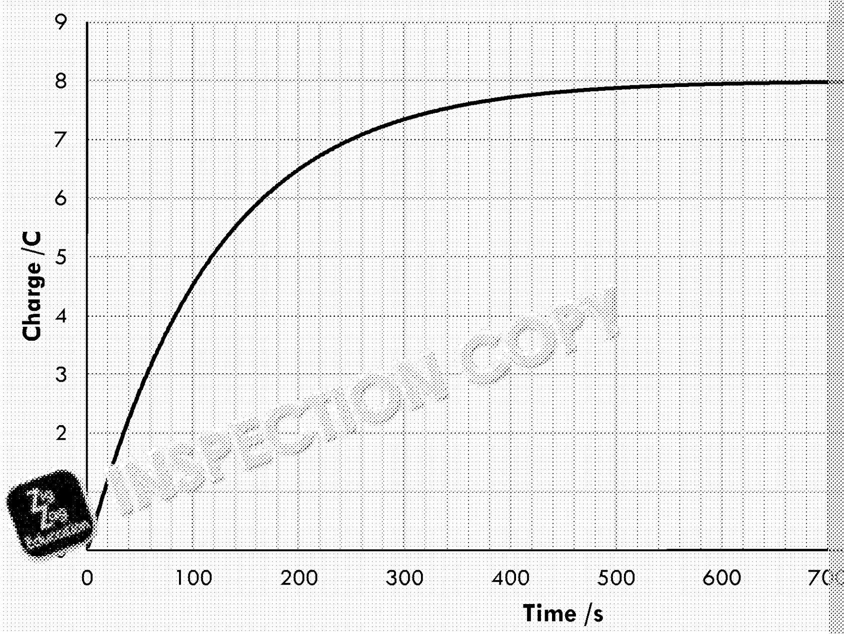
Substitute in values

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

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

Example 2

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



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 cha*

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

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

$RC = 116$ s

Alternatively, we can look directly for RC, which is the time taken for a cap
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

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

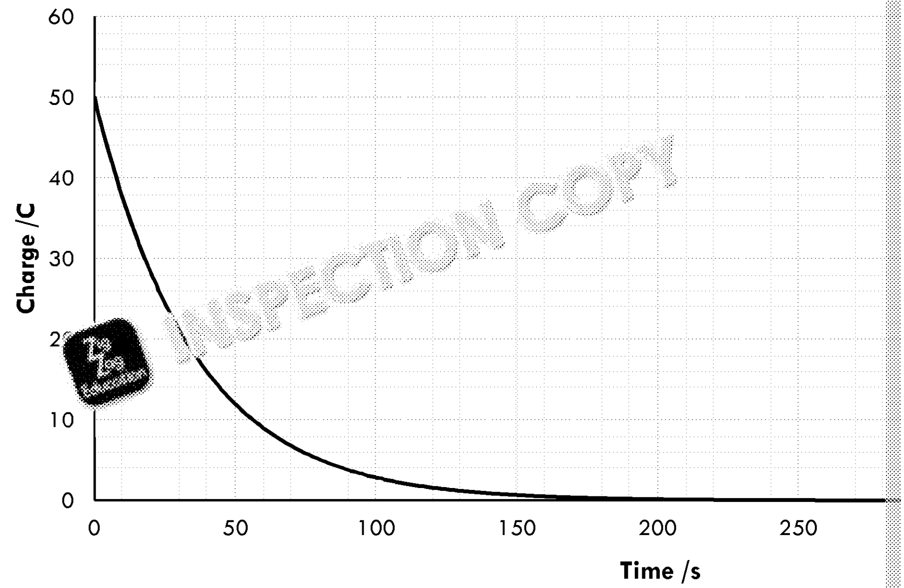
C = 0.0038 F = 3

QUESTIONS

Bright spark

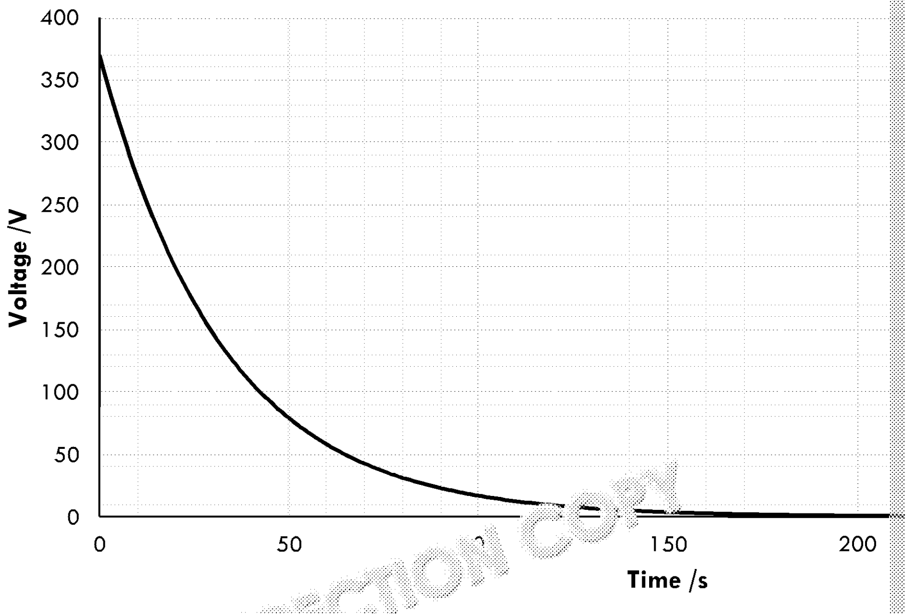
1. A capacitor discharges with a time constant of 38 s with an initial curre
   Calculate the current out of the capacitor after one minute.

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 resi[illegible]e resistor in kΩ.

4. A 400 [illegible]pacitor discharges through a resistor from an initial potenti

   It takes 108 s to reach 100 V.

   Calculate the resistance of the resistor in kΩ.

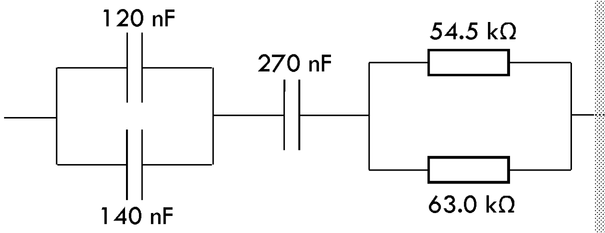
5. A capacitor is charged through a 24.5 kΩ resistor.

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

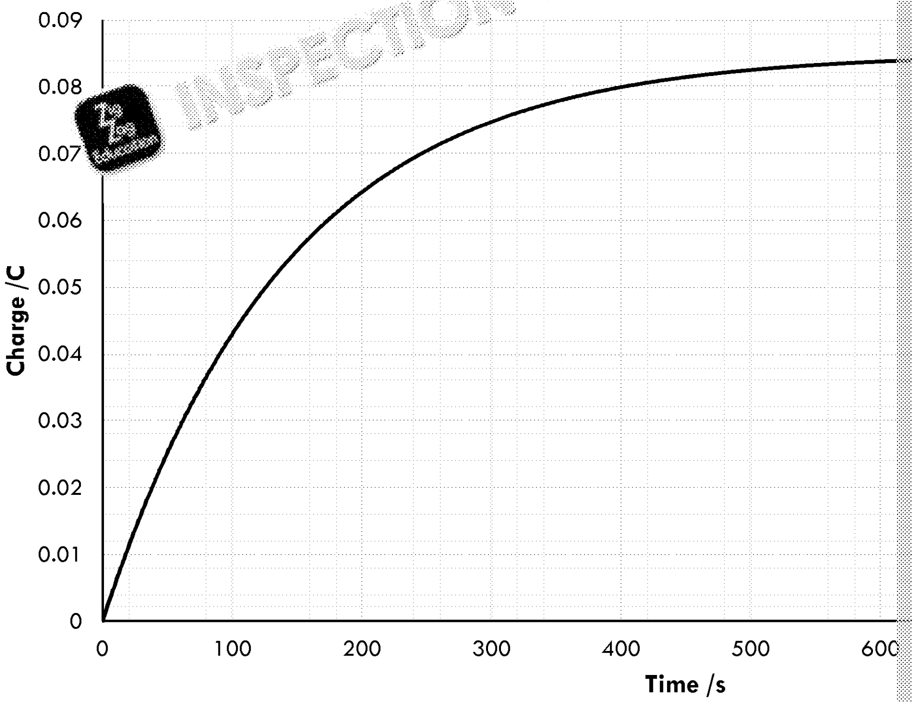
   Calculate the capacitance of the capacitor.

Shocking!

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



7. The graph below 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 cap compared to its initial value.

10. TRANSFORME

6.3.3: ELECTROMAGNETISM

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 may require a specific potential differen[...] [...]unction.

The relationship between the number [...] in [...]e coils of a transformer and the potentia[...] [...] 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

The efficiency of a transformer is given by

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

EXAM TI
Efficiencie
percenta
decimal i

For exam
equivalen

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 of 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 side*

Then substitute in values

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

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

Example 2
A transformer is 80 % efficient.
The primary coil of a transf[...]er [...] connected to a 50 V [...] [...]pply, and has 8[...] [...]n[...] [...]rough it.

The second[...] coil provides 90 V.

Calculate current through the secondary coil.

We ne[...] [...]se

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

with $efficiency = 80\ \% = 0.8$, $V_p =$

$I_p = 80$ A and $V_s = 90$ V.

Rearrange for I_s

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

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

$\mathbf{I_s = 36\ A}$

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 in the secondary coil.

We need to use

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

but we don't have anything in the corre

$efficiency = 75\ \% = 0.75,\ V_p = 300$ V,

$N_s = 15.$

IV actually gives us the power transfer 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 need

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

which rearranges for V_s

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

Substituting in values gives

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

$V_s = 56.25$ V

and substituting values into our earlier e

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

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

$\mathbf{I_s = 12\ A}$

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 secondary coil.

2. A transformer has a current of 130 mA running through its primary coil [illegible] secondary coil.

   The potential difference across the primary coil is 7.5 kV and across the [illegible]

   Calculate the efficiency of the transformer.

Charging up

3. A transformer is [illegible] % efficient. The potential difference across the s[illegible] 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 [illegible] secondary coil is 700.

   The current through the primary coil is 84.3 A and the current through th[illegible]

   Calculate the efficiency of the transformer.

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

   The efficiency of the transformer is 90.0 %.

   The resistance of the secondary coil is 77.3 Ω.

   Calculate the current through the secondary coil.

Shocking!

6. There is a potential difference of 230 V across the primary coil of a tra[illegible] 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[illegible] resistance of 77.8 Ω.

   Calculate the efficiency of the transformer.

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

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

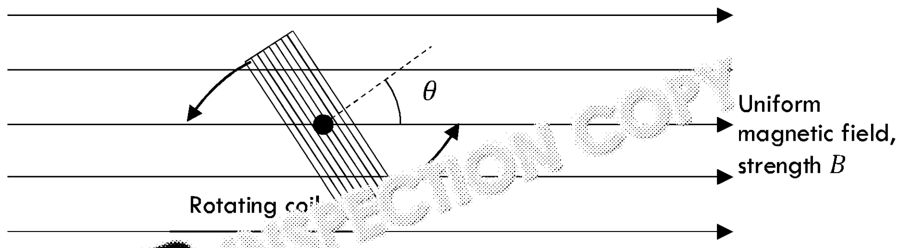
   Calculate the current in the secondary transformer.

11. ELECTRICITY GENE

6.3.3: ELECTOMAGNETISM

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

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

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.

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 m².

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

The coil's cross-section initially makes an angle of [illegible] 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 $\varepsilon = N\frac{\Delta\Phi}{\Delta t}$

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

$N\Phi = BAN\cos\theta$

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

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

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

$\Delta\Phi = -0.0158$ T m²

Putting this into our original equ

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

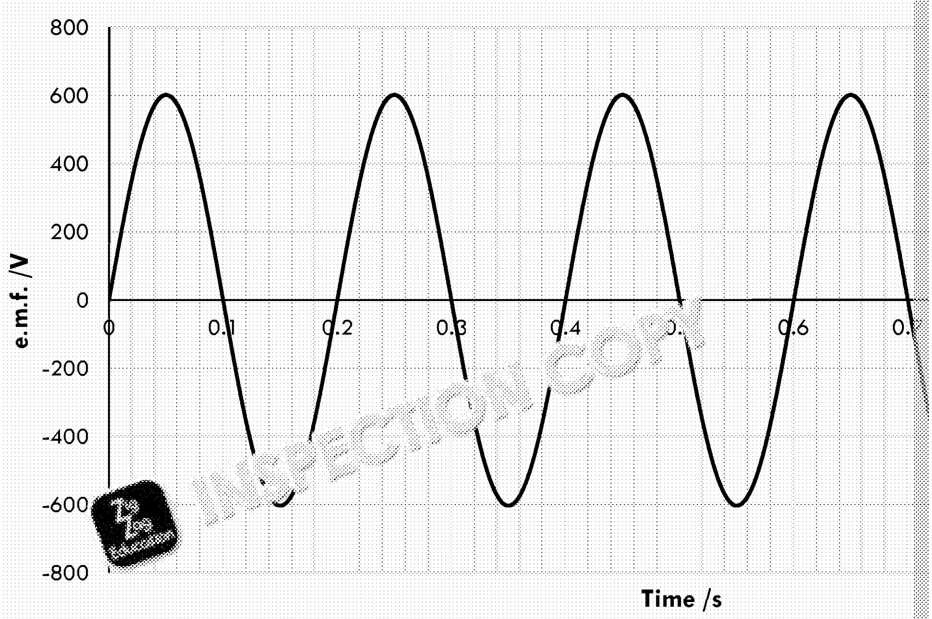
$\varepsilon = 80 \times \frac{-0.0158}{15}$

$\varepsilon = -0.084$ V

EXAM
A neg
the cu
from th

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 $\omega t = 2\pi$

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

$\omega = 31.4$ rad 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

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

***N* = *1530* turns**

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

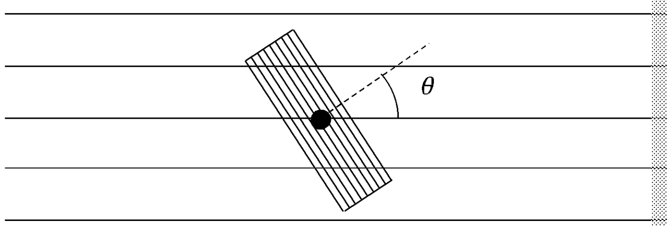
   Calculate the e.m.f. induced in the coil.

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

   Calculat[illegible] [illegible]erated in the coil one minute after it starts rotat[ing] cross-[illegible] fa[illegible]ng the magnetic field.

Charging up

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

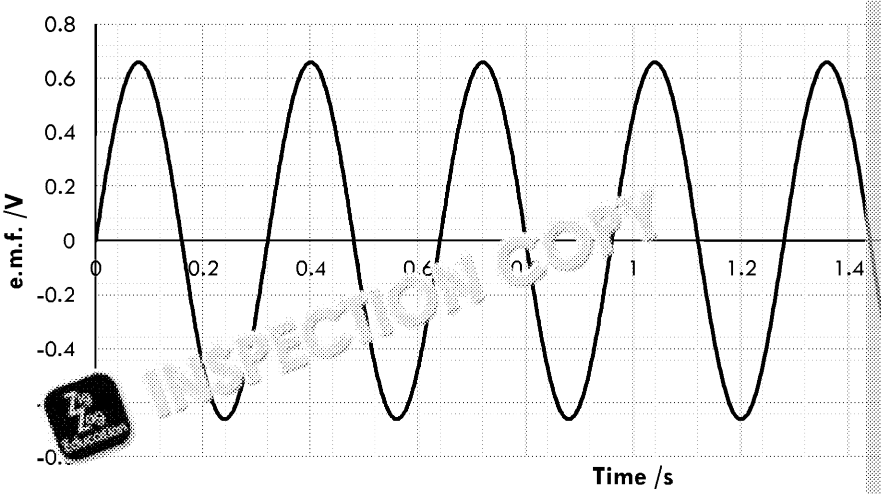


   At $t = 0$, $\theta = 0°$. At $t = 2.50$ s, $\theta = 36°$.

   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.

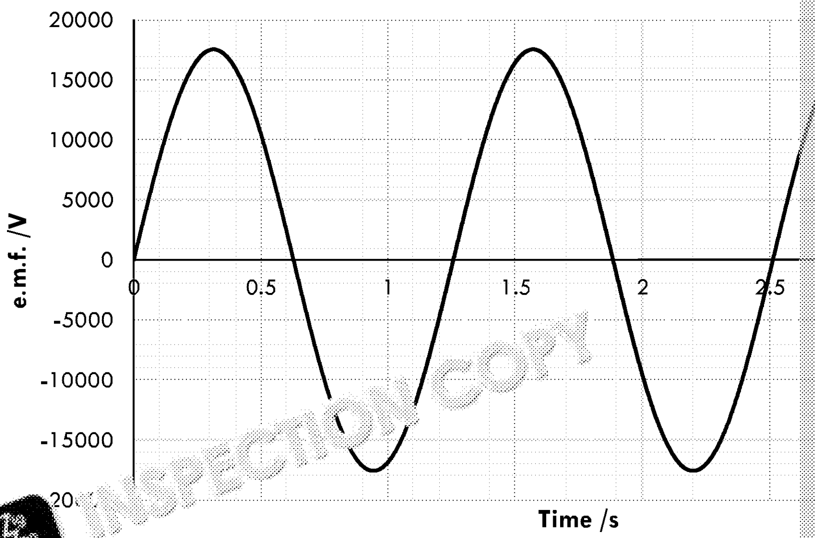
6. A coil has 50 turns and a cross-sectional area of 300 mm² and is place[d] perpendicular to a magnetic field of magnetic field strength 20 mT.

   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!

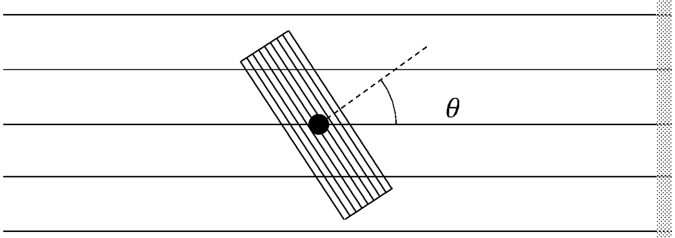
7. The graph below shows the e.m.f. of a coil rotating in a magnetic field.



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

Calculate the magnetic field strength.

8.



The coil shown 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.

12. ELECTROMAGNETIC PH

6.3.3: ELECTROMAGNETISM

BACKGROUND

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

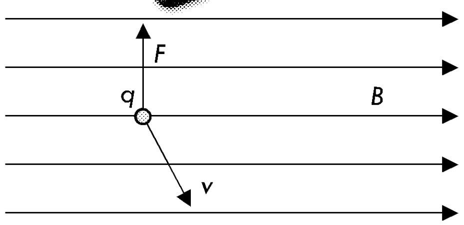
Lorentz force

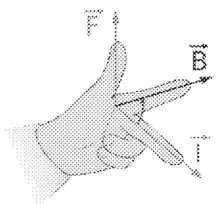
The Lorentz force is the force felt by a moving charge in a magnetic field.

The force felt by a moving charge is given by

$$F = Bqv$$

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





Hold your left han

- Your thumb r **force felt.**
- Your first fing **the magnetic**
- Your second f **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 your 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 condu

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 pass through the tube than it would do 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 rat 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 **Lorentz f**

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

Example 2

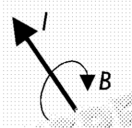
A solenoid consists of a wire wrapped into a coil.

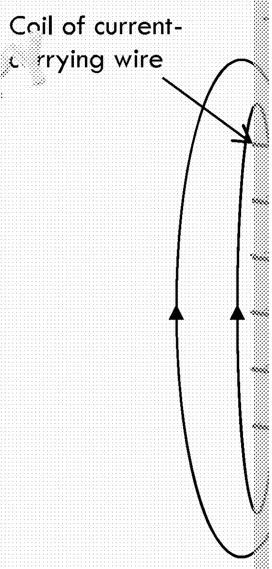
A current flows through the solenoid, generating a magnetic field.

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

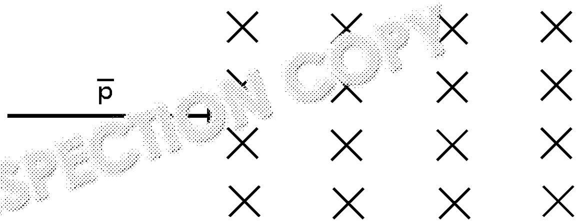
1. Two wires lie next to each other, with currents facing in the same directi

   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 for backwards due to Earth's magnetic field.

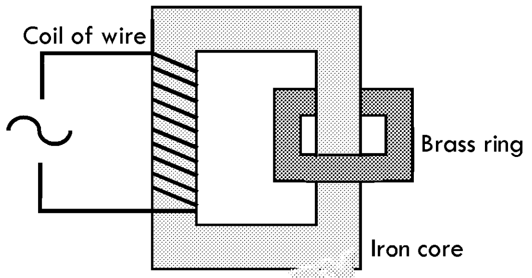
4. Two identical copper balls are dropped through two metal tubes.

   Both tubes are identical, except one is made of copper and one is mad 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.

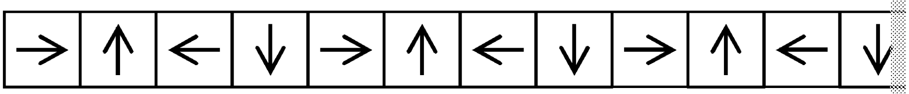


   Describe and explain the effect of an AC current being applied through

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 magnets.

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



EXAM-STYLE QUESTIONS

1. **Fig. 1.1** shows a circuit.

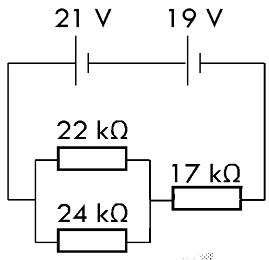


Fig. 1.1

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

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

The 19 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 1.3 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

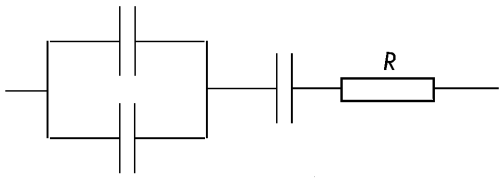


Fig. 3.1

(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 **Fig. 3.1**.

(c) The capacitors discharge through the resistor, producing the graph seen in **Fig**

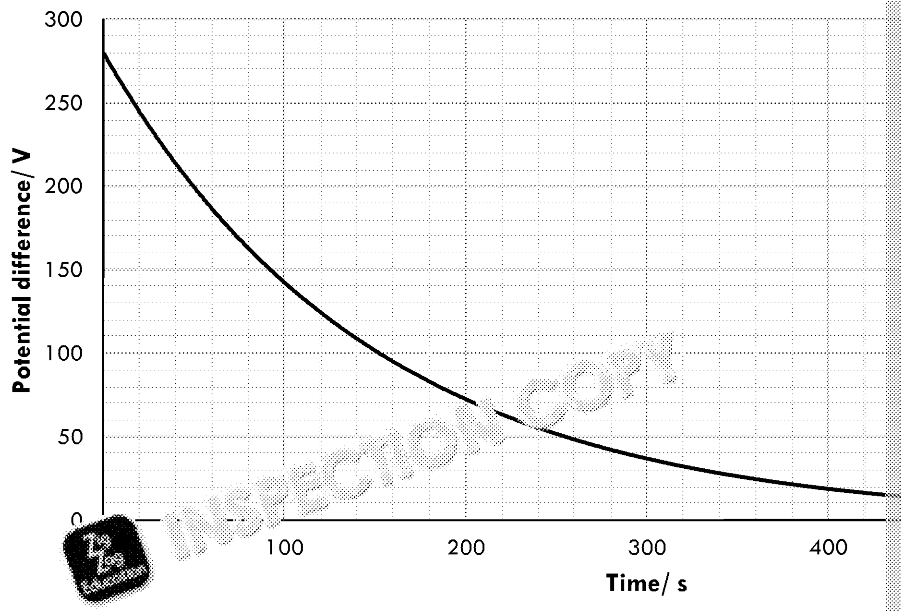


Fig. 3.2

Calculate the value of *R*.

4. A coil with a cross-sectional area of 0.16 m^2 and 320 turns rotates in a magn strength *B*, producing the graph seen in **Fig. 4.1**.

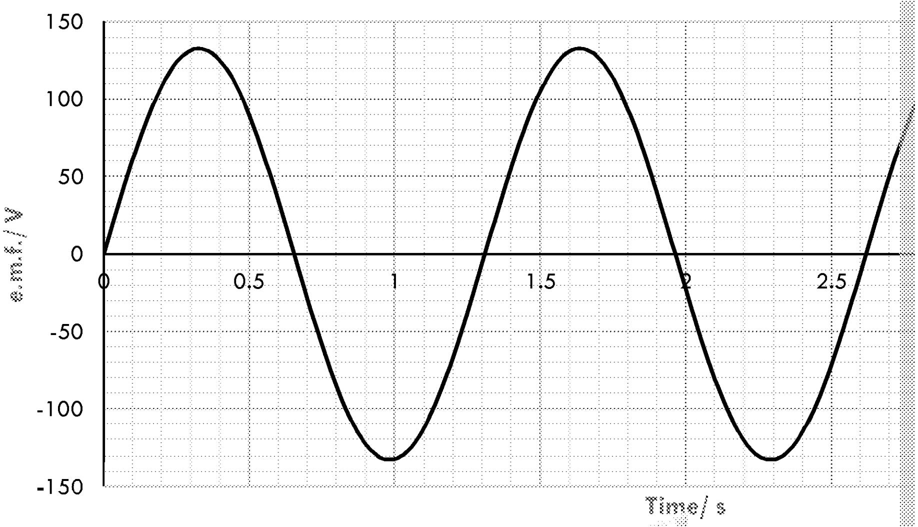


Fig. 4.1

(a) Calculate the angular freque coil.

(b) Calculate the

(c) Th produced is put through a transformer with 75 turns on the pri sec ry coil.

The current through the primary coil of the transformer is 210 mA, and th

Calculate the current through the secondary coil of the transformer.

(d) The potential difference across the secondary coil of the transformer is d vertical divisions and 12 horizontal divisions.

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

ANSWERS

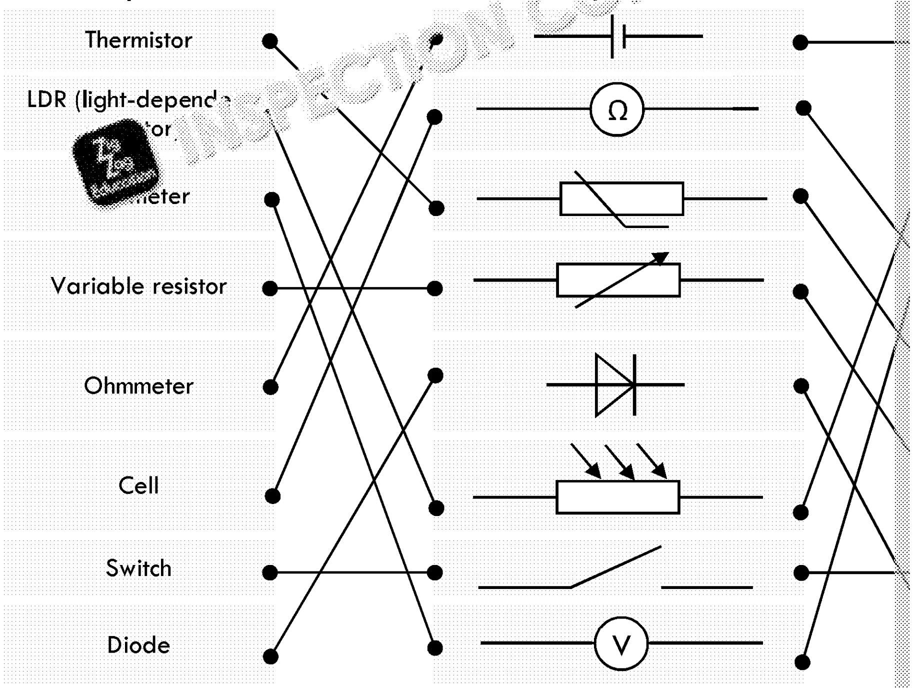
GCSE POP QUIZ

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 through it.

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

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

4. **Component** **Symbol**



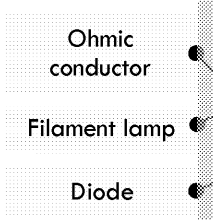
5. $V = IR$
$R = \frac{V}{I} = \frac{52}{850 \times 10^{-3}} = 61\ \Omega$

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.

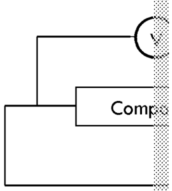
7. $I_{in} = I_{out}$
$8.5 + 6.3 = 4.1 + I$
$I = 8.5 + 6.3 - 4.1 = 10.7$ A

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 from a power source is equal to **the potential difference lost in the circuit.**

9.



10.



11. a) $P = I^2 R = (190 \times 10^{-3})^2 \times 220 = 7.9$ 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. Tra
voltage of electricity for use in h

13. Generate electricity for the Nati
convert motion to electricity for l
vibrations to signals

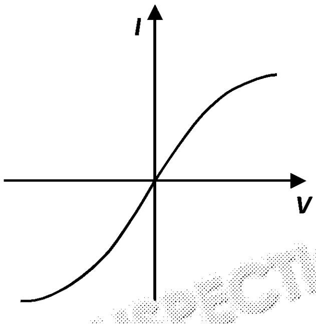
1. I–V CHARACTERISTICS

Bright spark

1. As metal heats up, its resistance increases.

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

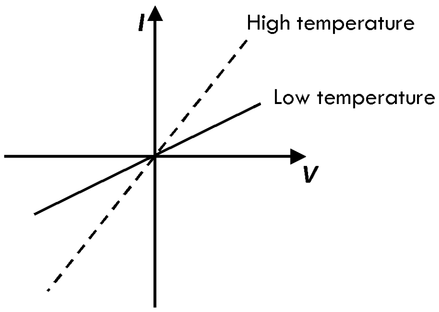
   At higher currents (and temperatures), resistance increases and the gradient of an *I–V* graph decreases.



2. Curren ws above a threshold potential difference (V_0) or c high negative potential differences. Resistance decreases with increasing current.

Charging up

3.



   A thermistor's resistance decreases with temperature. For an *I–V* graph, $gradient \propto \frac{1}{R}$ so a lower resistance means a higher gradient.

4. • Place ammeter i
   voltmeter in par
   • Take readings o
   • Repeat with incr

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

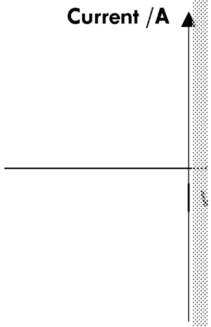
   Gradient at tangen

   Gradient = *0.76*

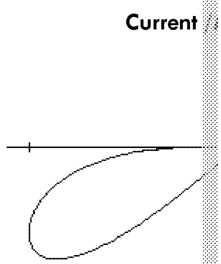
   $R = 1.3\ \Omega$

hocking!

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



7.



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

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

$L = \frac{92.3 \times 10^{-3} \times 7.07 \times 10^{-6}}{6.72 \times 10^{-7}}$

$L = 0.971$ m

Charging up

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

$\Delta R = \frac{\rho}{A}$ ...)

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

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

$\rho = 0.118\ \Omega$ 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

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

$R_2 = \frac{2.20 \times 10^{-7} \times 0.230}{\pi \times (9.31 \times 10^{-2})^2 - \pi \times (6.64 \times 10^{-2})^2}$

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

Total

$R = R_1 + R_2$

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

Shocking!

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

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

$R_{carbon} = 4.018\ \Omega$

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

$R_{aluminium} = 49.87$ m...

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

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

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

$R_{total} = 8.295$ mΩ

$P = I^2R$

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

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

6. $A = \pi r^2$

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

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

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

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

$\rho = 51.29$ mΩ m

Cross-section of new ...

$V = L_1A_1$

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

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

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

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

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

Resistance of new cy...

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

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

$R_2 = \frac{51.29 \times 10^{-3} \times 5.4\ldots}{2.128 \times 10^{\ldots}}$

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

Bright spark

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

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

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

   $R = 1300\ \Omega$

2. $P = I^2R$

   $E = Pt$

   $E = I^2Rt$

   $E = (77.1 \times 10^{-3})^2 \times 38.6 \times 10^3 \times$ [illegible]

   $E = 63.8$ kJ

Charging up

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

   $E = Pt$

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

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

   $E = 416.9 \times 10^3$ J

   $E_{grav} = mgh$

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

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

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

   $efficiency = \frac{E_{grav}}{E}$

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

   efficiency = 0.696 or 69.6 %

4. $P = I^2R$

   $E = Pt$

   $E = I^2Rt$

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

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

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

   Q = [illegible]

   Q = 0.3[illegible]

Shocking!

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

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

   $I^2R = 262.8$ kW

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

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

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

   efficiency = 0.991 o…

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

   $E_k = \frac{1}{2} \times 1035 \times 68\ldots$

   $E_k = 2.435 \times 10^6$ 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

   $E = Pt$

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

   $E = 3.869 \times 10^6$ J

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

   $efficiency = \frac{E_k}{E}$

   $efficiency = \frac{2.435 \times 1\ldots}{3.869 \times 1\ldots}$

   efficiency = 0.629 o…

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

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

   $R_{total} = \frac{1}{1/3.98 + 1/2.22 + 1/4.01 + 1/3.53 + 1/2.80}$

   $R_{total} = 0.628\ \Omega$

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

   $V_1 = IR_{total}$

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

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

   $R_{total} = 29.34\ \Omega$

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

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

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

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

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

   $R = 141\ \Omega$

6. $V = IR$

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

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

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

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

   $60 + 5R_1 = 240 + \ldots$

   $R_1 = 36 + 4R_2$

   $26 = 0.25\ (36 + 4R_2 \ldots$

   $26 = 9 + 1.25R_2$

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

   $R_1 = 36 + 4R_2$

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

5. 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, $I_{total} = I_1 + I_2 + I_3 + \ldots$

   $I_{cell} = \frac{1.38}{54}$

   $I_{cell} = 0.026$ A

   $I_{cell} = 26$ mA

2. For cells in series, ε_{to} [illegible] $\varepsilon_3 + \ldots$

   $\varepsilon_{total} =$ [illegible] 5 [illegible] 54

   $\varepsilon_{total} =$ [illegible]

   $\varepsilon = IR$

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

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

   $I = 14$ 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.

   $80 = 50 \times I_1 + 10$

   $160 = 75 \times I_2 + 1$

   (1) ×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

   $I_3 = I_1 + I_2 = 1.11$

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

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

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

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

   $V_{in} = 65.0 \times \frac{1.30 \times 10^3 + 2.95 \times 10^3}{1.30 \times 10^3}$

   $V_{in} = 213$ V

Charging up

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

   $R = \frac{V}{V_{in}}$

   $R = \frac{34.6 \times 35}{65 - 34.6}$

   $R = 154\ \Omega$

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}

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

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

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

   For $V_{out} = 54.1$ V

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

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

   $R_{LDR} = 3735$ kΩ

   $R_{LDR} \propto I^3$

   R_{LDR} decreases by

   I changes by a facto

   $0.6779 \times 30.0 = 2$

7. DIELECTRICS

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

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

   $V = \frac{81.4 \times 10^{-3}}{185 \times 10^{-6}}$

   $V = 440$ V

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

   $E = \frac{1}{2}\frac{Q}{C}$

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

   $E = 17.9$ J

Charging up

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

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

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

   $E = \frac{1}{2} \times 249 \times 10^{-6} \times (41.6 \times 10^{-3} \times 341)^2$

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

4. $E = \frac{1}{2}QV$

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

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

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

   $C = \frac{\pi \times (7.24 \times 10^{-2})^2 \times 8.85 \times 10^{-12} \times 6.84 \times 10^{11}}{14.1 \times 10^{-2}}$

   $C = 0.7070$ F

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

   $E = 2550$ J

   $E = 2.5$…

Shocking!

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

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

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

   $C = \frac{2E}{V^2}$

   $C = \frac{2 \times 5.51 \times 10^{9}}{(6.14 \times 10^{8})^2}$

   $C = 2.923 \times 10^{-8}$ F

   $d = \frac{134 \times 10^{6} \times 8.85 \times 10^{-12} \times 1}{2.293 \times 10^{-8}}$

   $d = 40.6$ km

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

   $Q = CV = C \times \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{Q}{R_2 - R_1}$

   $C = 4\pi\varepsilon_0\varepsilon_r(R_2 - R_1)$

   $C = 4\pi \times 8.85 \times 10^{-12} \times 3$…

   $C = 0.138$ 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. $\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4}$

   $\frac{1}{C_{total}} = \frac{1}{255 \times 10^{-12}} + \frac{1}{310 \times 10^{-12}} + \frac{1}{415 \times 10^{-12}} + \frac{1}{220 \times 10^{-12}}$

   $\frac{1}{C_{total}} = 1.410 \times 10^{10}$

   $C_{total} = 70.9$ pF

   $[p = 10^{-12}]$

   $C_{total} = 7.09 \times 10^{-11}$ 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. $C_{total} = C_1 + C_2 + C_3$

   $C_{total} = 550 \times 10^{-6} + 610 \times 10^{-6} + 480 \times 10^{-6}$

   $C_{total} = 1640$ μF

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

   $V = \sqrt{\frac{2E}{C}}$

   $V = \sqrt{\frac{2 \times 6.36}{1640 \times 10^{-6}}}$

   $V = 88.1$ V

Shocking

5. $E = \frac{1}{2}\frac{Q^2}{C_{total}}$

   $C_{total} = \frac{1}{2}\frac{Q^2}{E}$

   $C_{total} = \frac{1}{2}\frac{(382 \times 10^{-\ldots})}{65.0}$

   $C_{total} = 1.122 \times 1\ldots$

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

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

   $\frac{1}{C_2 + C} = \frac{1}{1.122 \times 10^{-3}} - \ldots$

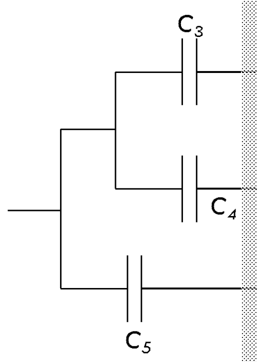
   $\frac{1}{C_2 + C} = 875.7$

   $C_2 + C = 1.142 \times \ldots$

   $C = 1.142 \times 10^{-3} \ldots$

   $C = 1.06$ mF

6. The circuit describe…



$C_{total} = C_{top} + C_5$

$\frac{1}{C_{top}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$

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

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

$\frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3 + C_4}} = C_{\ldots}$

$\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3 + C_4} = \ldots$

$\frac{1}{C_1} = \frac{1}{C_{total} - C_5} - \frac{1}{C_{\ldots}}$

$C_1 = \frac{1}{\frac{1}{C_{total} - C_5} - \frac{1}{C_2} \ldots}$

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. $V_0 = 370$ V

   $V_{RC} = 129.5$ V

   $RC = 32.5$ s

   $R = \frac{32.5}{45...}$

   $R = 72..$

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. $Q = Q_0(1 - e^{-\frac{t}{RC}})$

   $\frac{Q}{Q_0} = 1 - e^{-\frac{t}{RC}}$

   $e^{-\frac{t}{RC}} = 1 - \frac{Q}{Q_0}$

   $-\frac{t}{RC} = \ln(1 - \frac{Q}{Q_0})$

   $C = -\frac{t}{R \times \ln(1 - \frac{Q}{Q_0})}$

   $C = -\frac{64.3}{24.5 \times 10^3 \times \ln(1 - 0.819)}$

   $C = 1.54 \times 10^{-3}$ 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

   $Q = Q_0 e^{-\frac{t}{RC}}$

   $t = -RC \ln(\frac{Q}{Q_0})$

   $t = -29.22 \times 10^3 \times ...$

   $t = 0.685$ s

7. a) $Q_0 = 0.085$

   $Q_{RC} = 0.085 \times ...$

   $RC = 140$ s

   $C = \frac{140}{93.0 \times 10^3} ...$

   $C = 1.51 \times 1...$

   For $E = 1.81$ J...

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

   $Q = \sqrt{2EC} = \sqrt{...}$

   $Q = 0.0739$

   This value of Q...

   b) $V = V_0(1 - e^{...})$

   $\frac{V}{V_0} = 1 - e^{-\frac{t}{RC}} = ...$

   $\frac{V}{V_0} = 0.865 = ...$

10. TRANSFORMERS

Bright spark

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

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

$V_s = \frac{350 \times 140}{240}$

$V_s = 204$ V

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

$efficiency = \frac{670 \times 10^{-3} \times 450}{130 \times 10^{-3} \times 7.5 \times 10^{3}}$

$efficiency = 0.31$ or 31 %

Charging up

3. $efficiency = \frac{I_s V_s}{P_p}$

$I_s = efficiency \times \frac{P_p}{V_s}$

$I_s = 0.942 \times \frac{6.50 \times 10^{3}}{192}$

$I_s = 31.9$ A

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

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

$efficiency = \frac{37.6 \times 700}{84.3 \times 400}$

$efficiency = 0.78.1$ or 78.1 %

5. $efficiency = \frac{I_s V_s}{I_p V_p} = \frac{P_s}{P_p}$

$P = I^2 R$

$efficiency = \frac{I_s^2 R_s}{P_p}$

$I_s = \sqrt{efficiency \times \frac{P_p}{R_s}}$

$I_s = \sqrt{0.900 \times \frac{850}{77.3}}$

$I_s = 3.15$ A

Shocking!

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

$efficiency = \frac{V_s^2}{R_s} \times \frac{1}{I_p V_p}$

$N_s = 1.67 \times N_p =$ 1…

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

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

$V_s = \frac{230 \times 300}{180}$

$V_s = 383.3$ V

$efficiency = \frac{383.3^2}{77.8} \times$ …

$efficiency = 0.241$ o…

7. $P_p = \frac{V_p^2}{R_p}$

$V_p = \sqrt{PR}$

$V_p = \sqrt{985 \times 640}$

$V_p = 794.0$ V

$V_p = I_p R_p$

$I_p = \frac{V_p}{R_p}$

$I_p = \frac{794.0}{640}$

$I_p = 1.241$ A

Step-down transform…

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

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

$V_s = \frac{794.0}{1.76}$

$V_s = 451.1$ V

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

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

$I_s = 0.720 \times \frac{1.241 \times …}{45…}$

$I_s = 1.57$ A

11. 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. $\varepsilon = N\frac{\Delta\Phi}{\Delta t}$

   $\varepsilon = N\frac{A\Delta B}{\Delta t}$

   $\varepsilon = 38 \times \frac{12.6 \times 10^{-4} \times (93.7 \times 10^{-3} - 14.1 \times 10^{-3})}{60.0}$

   $\varepsilon = 6.35 \times 10^{-5}$ V

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

   $\omega = 170 \times \frac{2\pi}{60} = 17.80$ ra...

   $\varepsilon = 407$ ... $10^{-4} \times 120 \times 17.80 \times \sin(17.80 \times 60)$

   $\varepsilon = -13$...

Charging up

4. $\varepsilon = N\frac{\Delta\Phi}{\Delta t}$

   $N\Phi = BAN\cos\theta$

   $\varepsilon = \frac{BAN\Delta\cos\theta}{\Delta t}$

   $A = \frac{\varepsilon\Delta t}{BN\Delta\cos\theta}$

   $A = \frac{130 \times 10^{-3} \times 2.50}{84 \times 10^{-3} \times 85 \times (\cos 36 - \cos 0)}$

   $A = 0.238$ m²

5. Period $= 2\pi$

   $T = 0.32$ s

   $\omega t = 2\pi$

   $\omega = \frac{2\pi}{0.32}$

   $\omega = 19.6$ rad s⁻¹

6. $\varepsilon = N\frac{\Delta\Phi}{\Delta t}$

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

   $\Delta t = \frac{NBA}{\varepsilon}$

   $\Delta t = \frac{50 \times 20 \times 10^{-3} \times 300 \times ...}{70 \times ...}$

   $\Delta t = 4.$...

   $v = \frac{\Delta x}{\Delta t} = \frac{... \times 10^{-2}}{4.29 \times 10^{-3}}$

   $v = 35$ m s⁻¹

Shocking!

7. $T = 1.25$ s

   $\omega = \frac{2\pi}{T} =$ ...

   $\varepsilon = BAN\omega$ ...

   $BAN\omega = 17$...

   $B = \frac{17\,500}{AN\omega}$

   $B = \frac{17...}{1.80 \times ...}$

   $B = 0.644$ ...

8. $\varepsilon = N\frac{\Delta\Phi}{\Delta t}$

   $N\Phi = BAN$ ...

   $\varepsilon = \frac{BAN\Delta\cos...}{\Delta t}$

   $\Delta t = \frac{\Delta\theta}{\omega} =$ ...

   $\Delta t = 0.545$ ...

   $A = \frac{\varepsilon\Delta t}{BN\Delta\cos\theta}$

   $\Delta\cos\theta =$ ...

   $A = \frac{55.6 \times ...}{27.3 \times ...}$

   $A = 0.022$...

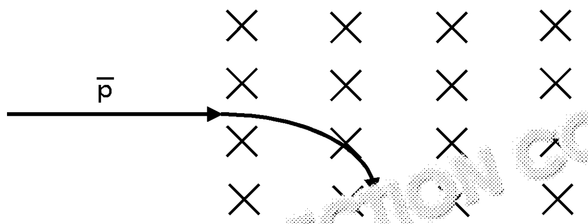
12. ELECTROMAGNETIC PHENOMENA

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 cha rie e ectrons) in the plane's metal frame are moving forwards with th simulati rent.

   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 t

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.

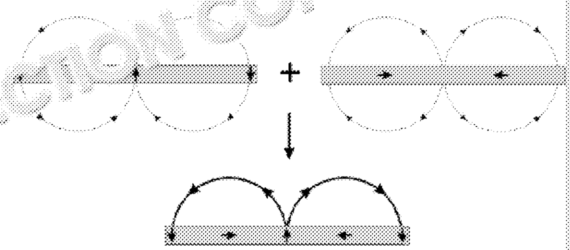
   This induces a current in the brass ring.

   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 could

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.

EXAM-STYLE QUESTIONS

1 a

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

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

$\frac{1}{R_{parallel}} = \frac{1}{22 \times 10^3} + \frac{1}{24 \times 10^3}$

$\frac{1}{R_{parallel}} = 8.71 \times 10^{-5}$ ✓

$R_{parallel} = 11500\ \Omega$

$R_{total} = 11500 + 17 \times 10^3$ ✓

$R_{total} = 28.5 \times 10^3\ \Omega$ ✓

b

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

$\varepsilon_{total} = 21 + 19$

$\varepsilon_{total} = 40$ [illegible]

[illegible] $+ r_1$

$r_{total} = r_1 + r_2$

$r_{total} = 0.68 + 0.34$

$r_{total} = 1.02\ \Omega$ ✓

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

$I = \frac{40}{28.5 \times 10^3 + 1.02}$ ✓

$I = 1.4 \times 10^{-3}$ A ✓

c

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

$P = (1.4 \times 10^{-3})^2 \times (28.5 \times 10^3 + 102)$ ✓

$P = 0.056$ W ✓

2 a

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

$\rho = \frac{1.1 \times 10^{-4} \times (8.3 \times 10^{-2})^2}{12 \times 10^{-2}}$ ✓

$\rho = 6.31 \times 10^{-6}\ \Omega$ m ✓

b

$V = A_1 L_1 = 12 \times 10^{-2} \times (8.3 \times 10^{-2})^2$

$V = 8.27 \times 10^{-4}$ m³ ✓

$A_2 = \frac{V}{L_2} = \frac{8.27 \times 10^{-4}}{1.3}$

$A_2 = 6.36 \times 10^{-4}$ m² ✓

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

$R_2 = \frac{6.31 \times 10^{-6} \times \text{[illegible]}}{6.\text{[illegible]}}$

[illegible]9 × $10^{-2}\ \Omega$ ✓

c

$P_{dissipated} = I^2 R$

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

$P_{dissipated} = \frac{P^2 R}{V^2}$ ✓

$P_{dissipated} = \frac{45^2 \times 1.29 \times 10^{-2}}{92^2}$ ✓

$P_{dissipated} = 3.1 \times 10^{-3}$ W ✓

3	**a**	$C = \frac{A\varepsilon_r\varepsilon_0}{d}$ $\varepsilon_r = \frac{dC}{A\varepsilon_0}$ ✓ $\varepsilon_r = \frac{6.5 \times 10^{-3} \times 850 \times 10^{-6}}{\pi \times (4.1 \times 10^{-3})^2 \times 8.85 \times 10^{-12}}$ ✓ $\varepsilon_r = 1.18 \times 10^{10}$ ✓
	b	$C_{parallel} = C_1 + C_2$ $C_{parallel} = 2 \times 850 \times 10^{-6}$ $C_{parallel} = 1.70 \times 10^{-3}$ F ✓ $\frac{1}{C_{total}} = \frac{1}{C_{series}} + \frac{1}{C_{parallel}}$ $\frac{1}{C_{total}} = \frac{1}{850 \times 10^{-6}} + \frac{1}{1.70 \times 10^{-3}}$ $\frac{1}{C_{total}} = 1770$ ✓ $C_{total} = 5.65 \times 10^{-4}$ [illegible]
	c	$\frac{V_0}{[illegible]}$ 280 [illegible] [illegible] 05 s ✓ $T_{1/2} = 0.69RC$ $R = \frac{T_{1/2}}{0.69 \times C}$ ✓ $R = \frac{105}{0.69 \times 5.65 \times 10^{-4}}$ ✓ $R = 270 \times 10^3\ \Omega$ ✓
4	**a**	$\omega T = 2\pi$ ✓ $\omega = \frac{2\pi}{T}$ $\omega = \frac{2\pi}{1.3}$ ✓ $\omega = 4.83$ rad s^{-1} ✓
	b	$\varepsilon = BAN\omega \sin \omega t$ $B = \frac{\varepsilon}{AN\omega}$ ✓ $B = \frac{135}{0.16 \times 320 \times 4.83}$ ✓ $B = 0.55$ T ✓
	c	$efficiency = \frac{I_s V_s}{I_p V_p}$ $efficiency = \frac{I_s N_s}{I_p N_p}$ ✓ $I_s = efficiency \times \frac{I_p N_p}{N_s}$ ✓ $I_s = 0.83 \times \frac{210 \times 10^{-3} \times 75}{110}$ ✓ $I_s = 0.12$ A ✓
	d	$Horizontal\ divisions = \frac{T}{number\ of\ divisions}$ $Horizontal\ divisions = \frac{1.3}{[illegible]}$ Horizontal divisi[illegible] div^{-1} ✓ $\frac{V_s}{[illegible]}$ $\frac{N_s}{[illegible]}$ [illegible] $\times \frac{N_s}{N_p}$ $V_s = 135 \times \frac{110}{75}$ $V_s = 198$ V ✓ $Vertical\ divisions = \frac{V}{number\ of\ divisions}$ $Vertical\ divisions = \frac{198}{8}$ Vertical divisions = 25 s div^{-1} ✓