Higher Physics

Electricity

Notes

Name…………………………………………………………

Key Area Notes, Examples and Questions

Other Notes

Key Area: Monitoring and Measuring a.c

Previous Knowledge

Know what is meant by the terms.

- Current
- Voltage
- Frequency

Success Criteria

1.1 I can describe alternating current (a.c.) as a current which changes direction and instantaneous value with time.

1.2 I can describe a direct current (d.c) as a current which has constant direction and value.

1.3 I can identify alternating currents and direct currents (d.c.) from their traces on an oscilloscope screen.

1.4 I understand the terms *peak voltage* and *root mean square (r.m.s) voltage*, *peak current* and *root mean square current.*

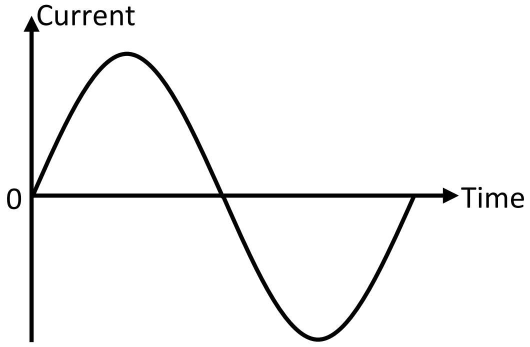
1.5 I understand what is meant by *time base* and *Y-gain* and can use these to find peak voltages and time intervals from an oscilloscope.

1.6 I can solve problems involving peak voltage, r.m.s voltage, peak current and r.m.s current.

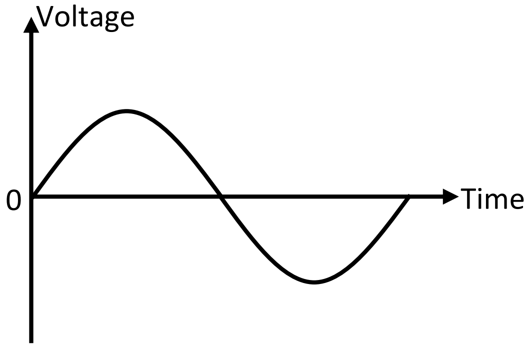
1.7 I can find the frequency of an a.c. supply from its trace on an oscilloscope screen.

1.1 I can describe alternating current (a.c.) as a current which changes direction and instantaneous value with time.

In an a.c. circuit the current is constantly changing value and direction. The graph shows that alternating current usually varies sinusoidally (shaped like a sine wave).

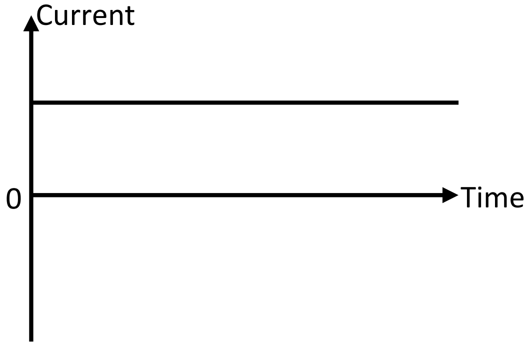


The current in an a.c. circuit is produced by an a.c. voltage which also varies sinusoidally.

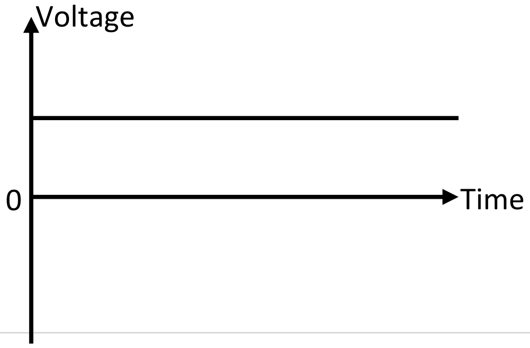


1.2 I can describe a direct current (d.c) as a current which has constant direction and value.

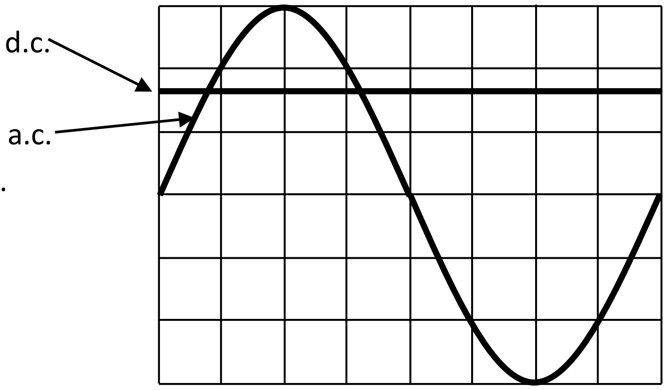
In a d.c. circuit the current has a constant value and direction.



The current in a d.c. circuit is produced by a d.c. voltage which is also constant.



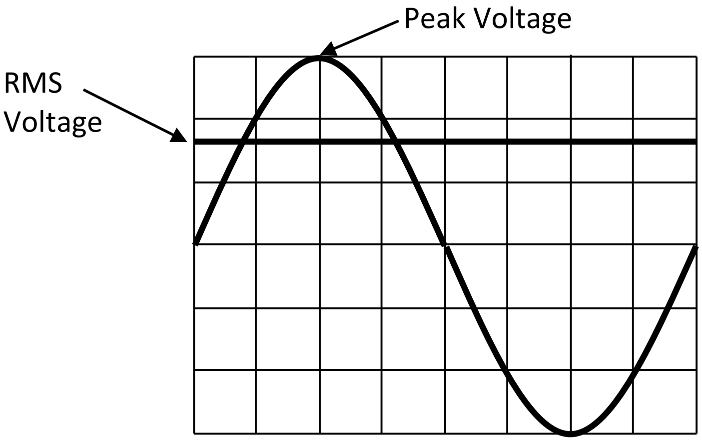
1.3 I can identify alternating currents and direct currents (d.c.) from their traces on an oscilloscope screen.



On an oscilloscope screen an a.c. signal appears as a sine wave. A d.c signal appears as horizontal line.

1.4 I understand the terms peak voltage, root mean square (r.m.s) voltage, peak current and root mean square current.

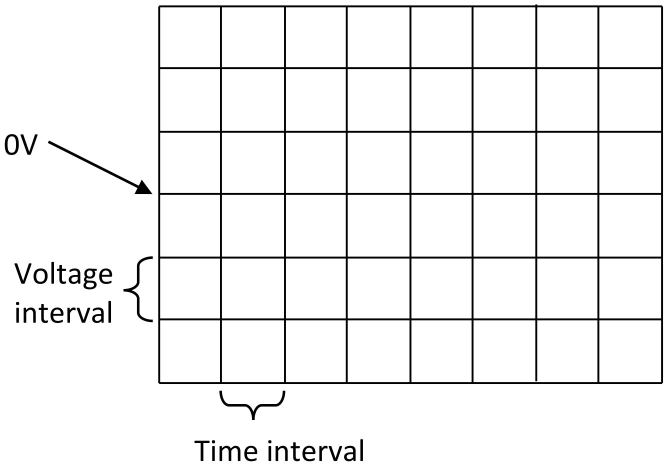
- Peak voltage is the greatest voltage value produced in an a.c. circuit.
- For any a.c. voltage its r.m.s. voltage is the equivalent d.c voltage that would dissipate the same power when connected to a load in a circuit.
- Peak current is the highest current produced in an a.c. circuit.
- In circuits containing resistors peak currents and peak voltages are related by Ohm's Law in the same way as d.c. currents and voltages.



1.5 I understand what is meant by *time base* and *Y-gain* and can use these to find peak voltages and time intervals from an oscilloscope.

Oscilloscope screens are marked with boxes usually about 1cm square. Each of these boxes is called a division.
Horizontally each division represents a time interval this called the **timebase**. The horizontal scale is usually given as time per division e.g. 2ms/div.

Vertically each division represents a voltage interval and is call the **Y-gain**. The vertical scale is usually given as volts per division. E.g. 3V/div. The zero for the vertical scale is usually in the centre of the screen.



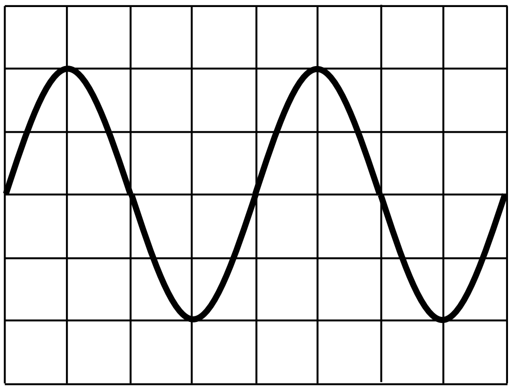
Example

For the oscilloscope shown the Y-gain of is set to 5V/div and the time base is set to 2ms/div

Find

a. The peak voltage of the signal.

b. the period of the signal.



Solution

a. The peak voltage is 2 divisions from the zero position.
$V_{peak} = 2 \times 5 = 10\text{V}$

b. One wave covers 4 divisions.
$\text{Period}, T = 4 \times 2 \times 10^{-3} = 0.008\text{s}$

1.6 I can solve problems involving peak voltage, r.m.s voltage, peak current and r.m.s current.

Peak and rms voltages are related by the relationship

$$V_{peak} = \sqrt{2}.V_{rms}$$

Peak and rms currents are related by the relationship

$$I_{peak} = \sqrt{2}.I_{rms}$$

<u>Example</u>

A capacitor has a maximum voltage rating of 25V. Can this capacitor be used in a circuit where the r.m.s. voltage of a power supply is 20V?

<u>Solution</u>

$V_{peak} = \sqrt{2}.V_{rms}$

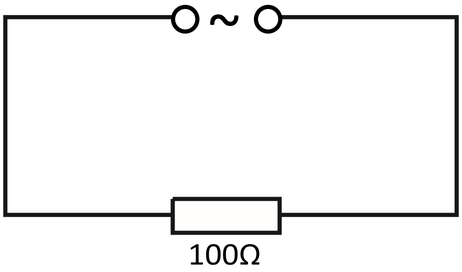
$V_{peak} = \sqrt{2} \times 20$

$V_{peak} = 28\text{V}$

As the peak voltage is greater than the rated voltage of the capacitor it cannot be used in the circuit.

<u>Example</u>

In the circuit shown the peak voltage of the power supply is 14.4V. Calculate the power dissipated by the resistor.



<u>Solution</u>

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

$$V_{rms} = \frac{14.4}{\sqrt{2}}$$

$$V_{rms} = 10.18\text{V}$$

$$P = \frac{V_{rms}^2}{R}$$

$$P = \frac{10.18^2}{100}$$

$$P = 1.04\text{W}$$

Problem book pages 5 questions 3 and 4 then page 4 question 2

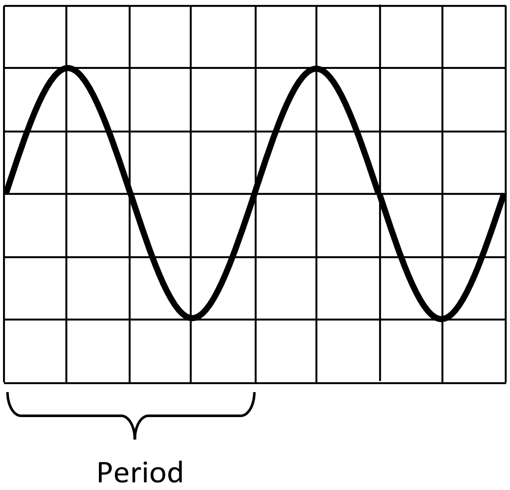
1.7 I can find the frequency of an a.c. supply from its trace on an oscilloscope screen.

The frequency of an a.c. signal can be calculated from its period using the relationship.

Frequency (Hz)

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

Period (s)



Example

Find the frequency of the waveform shown if the timebase is set at 10ms/div.

Solution

$$T = 4 \text{ divisions}$$
$$T = 4 \times 10 \times 10^{-3} = 4.0 \times 10^{-2}\text{s}$$

$$f = \frac{1}{T}$$
$$f = \frac{1}{4.0 \times 10^{-2}}$$

$$f = 25\text{Hz}$$

Question book page 4 question 1
Pages 5 and 6 question 5

Homework Alternating Current

Key Area: Current, Potential Difference, Power and Resistance

Previous Knowledge

- $Q = It$
- Ohm's Law, $v = IR$
- Power relationships, $E = Pt, P = VI = I^2R = \frac{V^2}{R}$
- Resistors in series and parallel relationships, $R_T = R_1 + R_2 + \cdots, \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$
- Electronic input and output devices from national 5.

Success Criteria

2.1 I can use appropriate relationships to solve problems involving potential difference, current, resistance and power where the solution may involve several steps.

2.2 I understand what a potential divider is and what they are used for in electronic circuits.

2.3 I can use appropriate relationships to solve problems involving potential divider circuits.

2.4 I know the purpose of the resistor used to protect and LEDs in circuit.

2.5 I can solve problems involving LEDs and resistors in circuits.

2.1 I can use appropriate relationships to solve problems involving potential difference, current, resistance and power where the solution may involve several steps.

In the National 5 course you learned to solve problems using the following relationships.

$Q = It$

Ohm's Law, $V = IR$

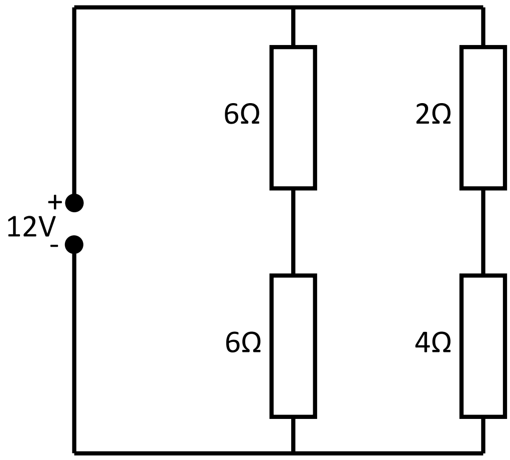
The Power relationships, $E = Pt, P = IV = I^2R = \frac{V^2}{R}$

Resistors in series, $R_T = R_1 + R_2 + \cdots$

Resistors in parallel, $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$

You are now expected to use these relationships solve problems involving several steps.

Example
Calculate the power dissipated by the circuit.



Solution
Step 1 Calculate the total resistance of the circuit.

Left branch $R_L = 6 + 6 = 12\Omega$
Right Branch $R_R = 2 + 4 = 6\Omega$

Total resistance

$$\frac{1}{R_T} = \frac{1}{R_L} + \frac{1}{R_R}$$

$$\frac{1}{R_T} = \frac{1}{12} + \frac{1}{6}$$

$R_T = 4\Omega$
Step 2 Calculate the power dissipated.

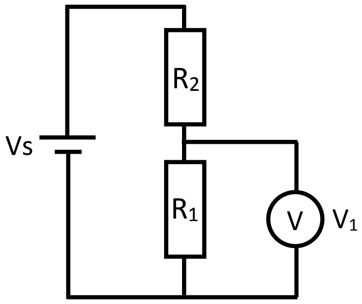
$$P = \frac{V^2}{R}$$

$$P = \frac{12^2}{4} = 36\text{W}$$

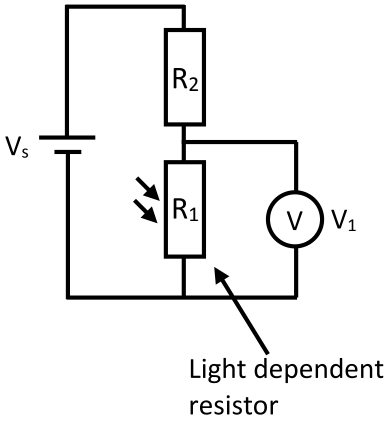
Problem book pages 6 to 9 questions 1 to 14

2.2 I understand what a potential divider is and what they are used for in electronic circuits.

A potential divider is a circuit usually containing two resistors which gives an output voltage (V_1) which is a fraction of the input voltage (V_S).



Potential dividers are used in electronic circuits where one of the two resistors will change its resistance when some other quantity changes. E.g. a thermistor where its resistance changes with temperature, a Light dependent resistor where its resistance changes with light level. This produces an output voltage which changes with the quantity (such as temperature) that changes.



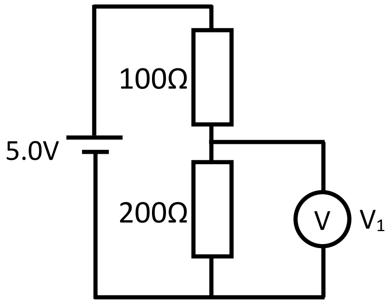
2.3 I can use appropriate relationships to solve problems involving potential divider circuits.

There are two relationships which are used for solving problems involving potential dividers

$$V_1 = \left(\frac{R_1}{R_1 + R_2}\right) V_s \qquad \frac{V_1}{V_2} = \frac{R_1}{R_2}$$

Where:
R_1 and R_2 are the resistance values
V_1 is the output voltage across R_1
V_s is the supply voltage

<u>Example</u>
In the in the circuit shown find the output voltage,V_1.



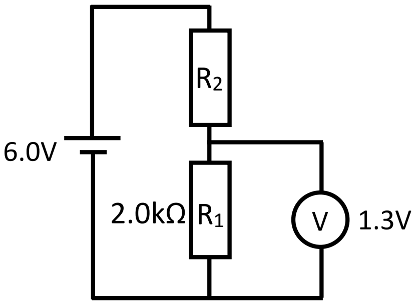
<u>Solution</u>
$V_s = 5.0\text{V}$
$R_1 = 200\Omega$
$R_2 = 100\Omega$

$$V_1 = \left(\frac{R_1}{R_1 + R_2}\right) V_s$$

$$V_1 = \left(\frac{200}{200 + 100}\right) \times 5.0$$

$$V_1 = 3.3\text{V}$$

<u>Example</u>
In the circuit shown find the value of the unknown resistor R_2.



<u>Solution</u>
$V_s = 6.0\text{V}$
$R_1 = 2.0\text{k}\Omega = 2000\Omega$
$V_1 = 1.3\text{V}$
$V_2 = ?$

As R_1 and R_2 are in series $V_2 = 6.0 - 1.3 = 4.7\text{V}$

$$\frac{V_1}{V_2} = \frac{R_1}{R_2}$$

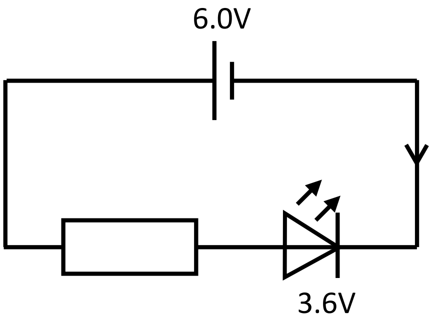
$$\frac{1.3}{4.7} = \frac{2000}{R_2}$$

$$R_2 = \frac{4.7 \times 2000}{1.3}$$

$R_2 = 7200\Omega$ (2 s.f.)

Problem book pages 10 and 11 questions 16 to 21

2.4 I know the purpose of the resistor used to protect and LEDs in circuit.

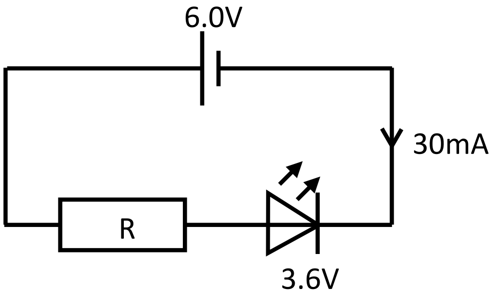


An LED will not limit the current passing through it. If an LED is connected in a circuit without a protective resistor the current passing through the LED will increase to the point where the LED is stops working.
The resistor limits the current in the circuit to protect the LED.

2.5 I can solve problems involving LEDs and resistors in circuits.

The value of the resistance used to protect and LED can be calculated from the current and voltage specification of the LED together with the voltage of the supply.

Example
An LED requires a current of 30mA and a voltage of 3.6V to operate correctly. Calculate the resistance of the protective resistor, R, when the power supply has a voltage of 6.0V.



Solution
As this is a series circuit the sum of the voltages across the components must add to the supply voltage. So the voltage across the resistor, V_R can be calculated from

$V_R + 3.6 = 6.0$

$V_R = 2.4\text{V}$

The resistance of the resistor can now be calculated using Ohm's Law.

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

Note
The voltage must be the voltage across the resistor.

$$R = \frac{2.4}{30 \times 10^{-3}}$$

$$R = 80\Omega$$

Problem book pages 9 and 10 question 15, page 29 question 8.

Key Area: Electrical Sources and Internal Resistance

Previous Knowledge

Ohm’s Law
Current and voltage rules in series circuits

Success Criteria

3.1 I know the meaning of the terms electromotive force (e.m.f), internal resistance, terminal potential difference (t.p.d), lost volts, ideal supply, short circuit and open circuit.

3.2 I can use an appropriate relationship to solve problems involving e.m.f, t.p.d, current and internal resistance.

3.3 I can state that the open circuit t.p.d. is equal to the e.m.f

3.4 Using graphical analysis, I can find the e.m.f, internal resistance and short circuit current of a power supply.

3.1 I know the meaning of the terms electromotive force (e.m.f), internal resistance, terminal potential difference (t.p.d), lost volts, ideal supply, short circuit and open circuit.

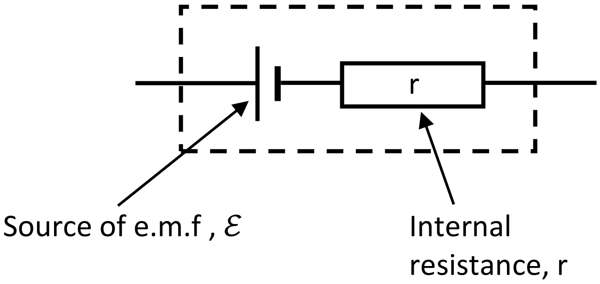
When used in a circuit any battery or power supply not only supplies energy to the resistance (load) in the circuit but also has its own internal resistance.

E.m.f. and Internal Resistance

Realistic Power Supplies

A battery or power supply is modelled as having two parts

- A source of e.m.f , $\mathcal{E}$, which supplies energy to the charges in the circuit. E.m.f. is defined as the energy in joules given to each coulomb of charge passing through the power supply. It is a voltage with units of Volts (V).
- An internal resistance, r, with units of Ohms (Ω).

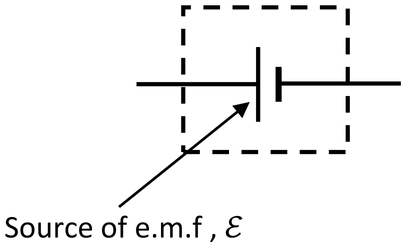


Ideal Power Supplies

This is where a power supply or battery is modelled as having zero internal resistance. The t.p.d. is always equal to the e.m.f.

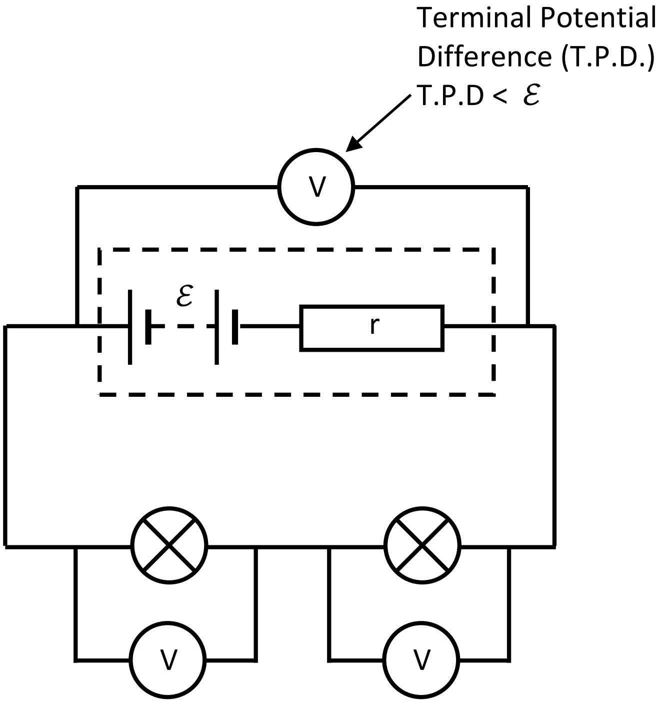
This can be a useful simplification when the current supplied to a circuit is low.

It can also be a realistic model for a regulated power supply where the electronics in the power supply keep the t.p.d. at a constant value.



Terminal Potential Difference, T.P.D

When part of a circuit, the voltage produced by an e.m.f will be distributed among the resistances in the circuit. As some of this voltage will be across the internal resistance, only part of the voltage produced by the e.m.f will be measured across the terminals of the battery or power supply.



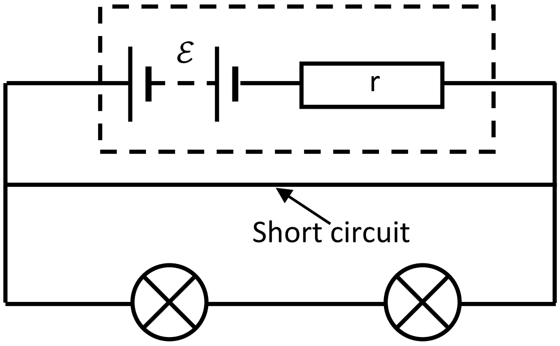
Lost Volts

The voltage across the internal resistance will not appear in the T.P.D. of the cell. This reduction in voltage is called lost volts. Lost volts is given by

$$\text{Lost Volts} = \mathcal{E} - \text{T.P.D.}$$

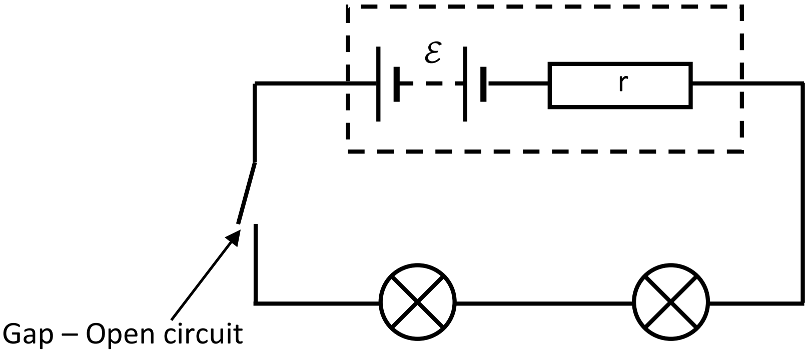
Short Circuit

This occurs when there is a direct connection between the terminals of a power supply or battery. As the internal resistance is usually low this leads to a high current in the circuit. Short circuits can damage electronic circuits and wiring as the high currents produced cause overheating.



Open Circuit

An open circuit is when there is a gap in the circuit which stops the flow of current. This is usually obtained by opening a switch.



3.2 I can use an appropriate relationship to solve problems involving e.m.f, t.p.d, current and internal resistance.

The relationship between e.m.f., t.p.d., current and internal resistance is given by

Current (A)

$$\mathcal{E} = V + Ir$$

Electromotive Force (e.m.f.) (V)

Internal Resistance (Ω)

Terminal Potential Difference (t.p.d.) (V)

The form of the relationship above will be the one given in the relationship sheet.

The term, *V* in this relationship can be replaced using Ohm's law to give

Current (A)

$$\mathcal{E} = I(R + r)$$

Electromotive Force (e.m.f.) (V)

Internal Resistance (Ω)

Load Resistance (Ω)

3.3 I can state that the open circuit t.p.d. is equal to the e.m.f

When there is an open circuit there is zero current in the circuit. By examining the relationship $\mathcal{E} = V + Ir$ it can be seen that

$$\mathcal{E} = V$$

Open circuit only

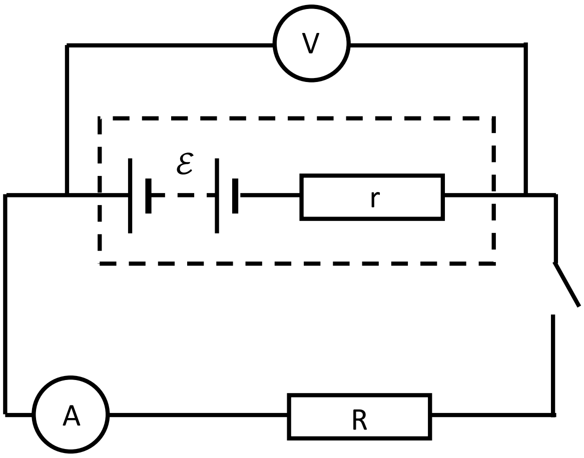
Electromotive Force (e.m.f.) (V)

Terminal Potential Difference (t.p.d.) (V)

The e.m.f of a battery or power source can be obtained by measuring the open circuit t.p.d.

Example

When the switch is open in the circuit shown the voltmeter reading is 3.0V. When the switch is closed the voltmeter reads 2.8V and the ammeter reads 0.9A.



a. Find the e.m.f. of the battery.

b. When the switch is closed what is the t.p.d. of the battery?

c. Find the resistance of resistor R and the internal resistance r.

d. The resistor R is changed to a variable resistor. The resistance is set at 3.0Ω, 2.0Ω, 1.0Ω. Draw a table giving the e.m.f., t.p.d., internal resistance and current at these three load resistance values.

e. Using the data from part d. state the relationships between.
(i) Load resistance, *R* and t.p.d.
(ii) Load resistance and current *I*.

Solution

a. E.m.f is given by the open circuit voltage, $\mathrm{e.m.f} = 3.0\mathrm{V}$.

b. T.p.d is the voltage across the terminals of the battery, $\mathrm{t.p.d} = 2.8\mathrm{V}$.

c.

$$V = IR \qquad \mathcal{E} = V + Ir$$

$$2.8 = 0.9R \qquad 3.0 = 2.8 + 0.9r$$

$$R = \frac{2.8}{0.9} \qquad r = \frac{3.0 - 2.8}{0.9}$$

$$R = 3.1\Omega \qquad r = 0.22\Omega$$

d. Both e.m.f. and internal resistance are fixed values.

To find *I and t.p.d. combine* $\mathcal{E} = V + Ir$ and $V = IR$ give $\mathcal{E} = I(R + r)$
$I = \frac{\mathcal{E}}{R+r}$ and $t.p.d, V = IR$

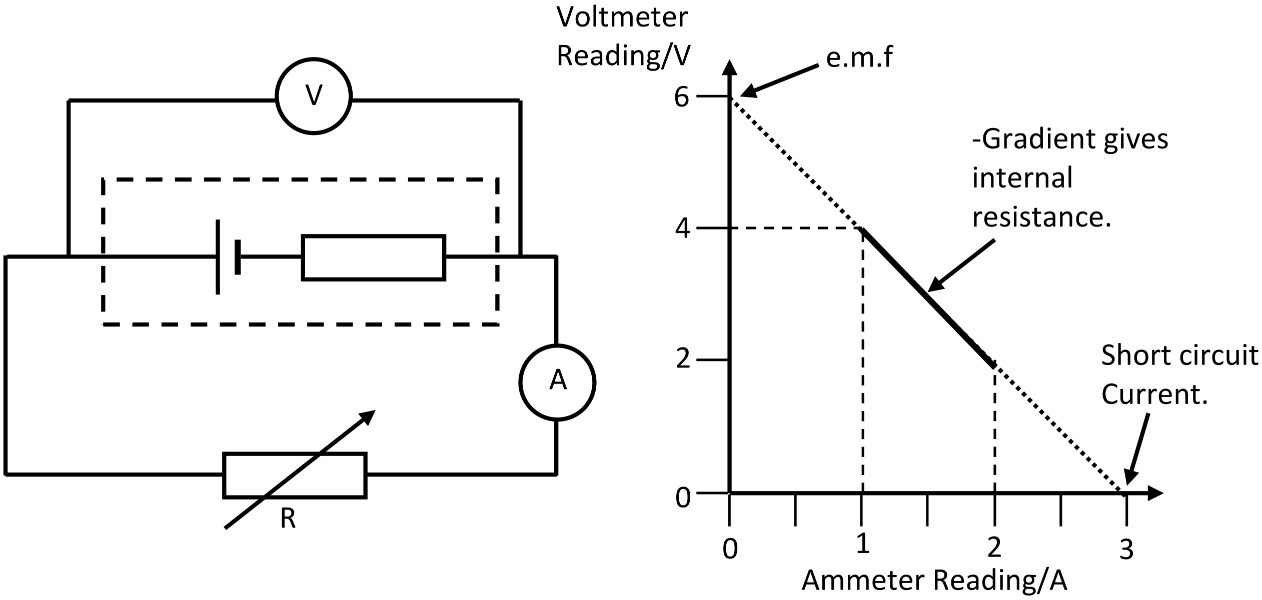
Load Resistance, R (Ω)	E.M.F (V)	T.P.D (V)	Internal resistance, r (Ω)	Current (A)
3.0	3.0	2.8	0.22	0.93
2.0	3.0	2.7	0.22	1.35
1.0	3.0	2.5	0.22	2.5

e. (i) As R decreases t.p.d decreases.
(ii As R decreases current increases.

Problem book pages 13 to 15 questions 6 to 13

3.4 Using graphical analysis, I can find the e.m.f., internal resistance and short circuit current of a power supply.

The e.m.f, internal resistance and short circuit current of a battery or power supply can all be obtained from a voltage (t.p.d.) current graph obtained using the circuit below. The variable resistor is changed to different values giving various current and t.p.d voltage readings. These are plotted and the solid line on the graph is obtained.



E.m.f. is obtained by extending the line to the voltage axis.

Short circuit current is obtained by extending the line to the current axis.

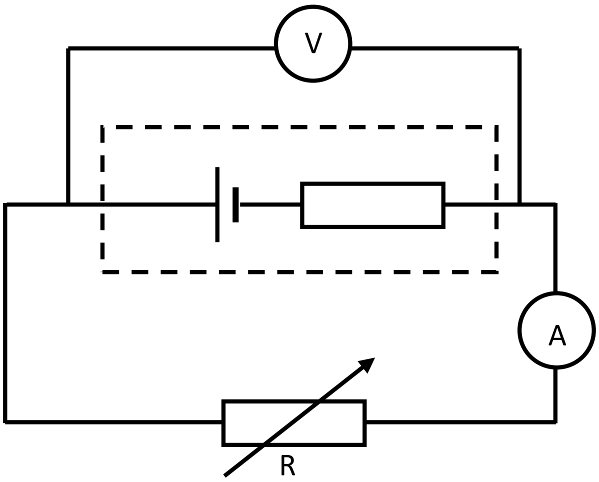
Internal resistance is obtained from the negative of the gradient of the line on the graph.

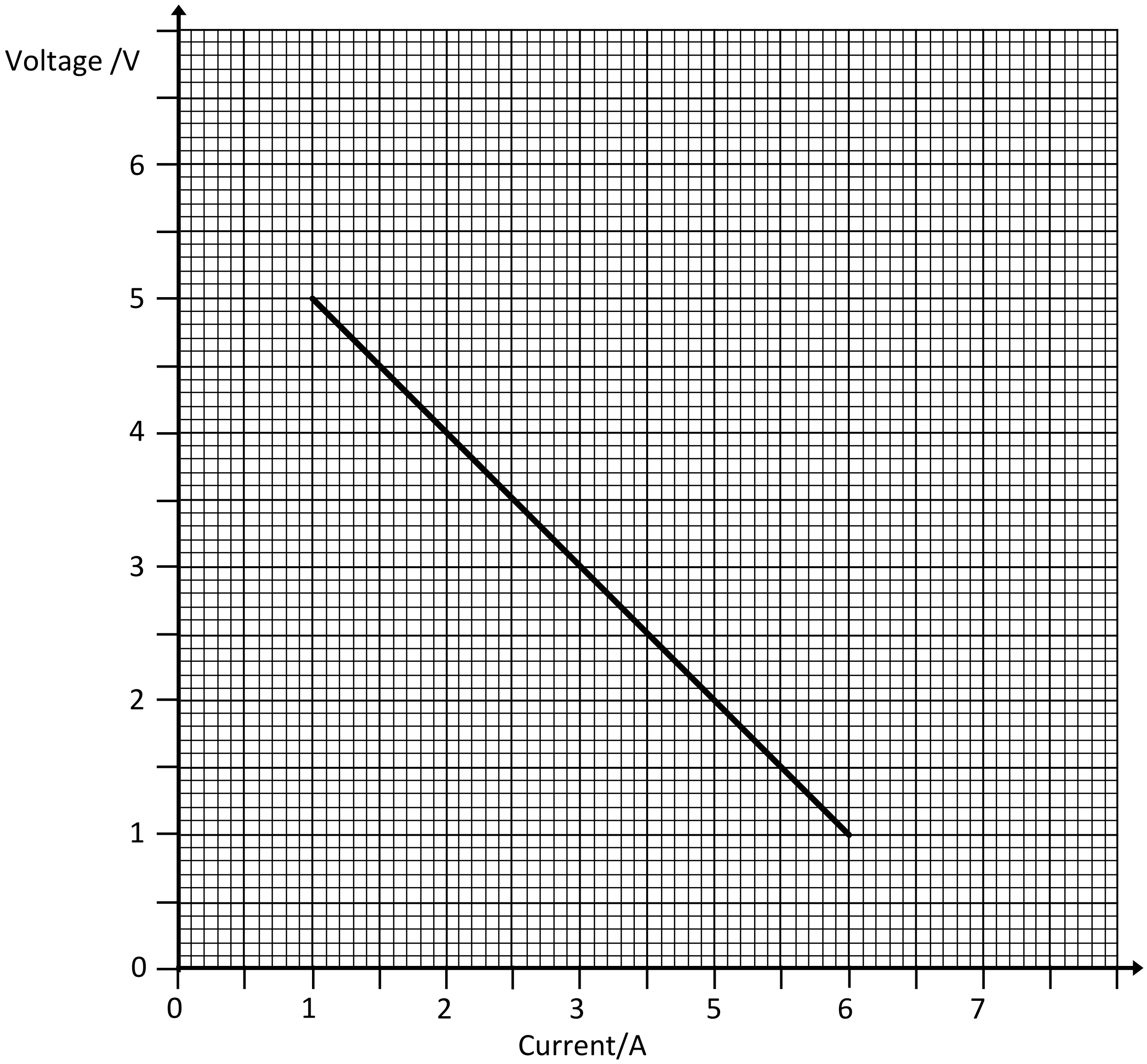
Example

In the circuit shown below the variable resistor is adjusted to various values. The readings obtained on the ammeter and voltmeter are plotted on the graph shown.

Find

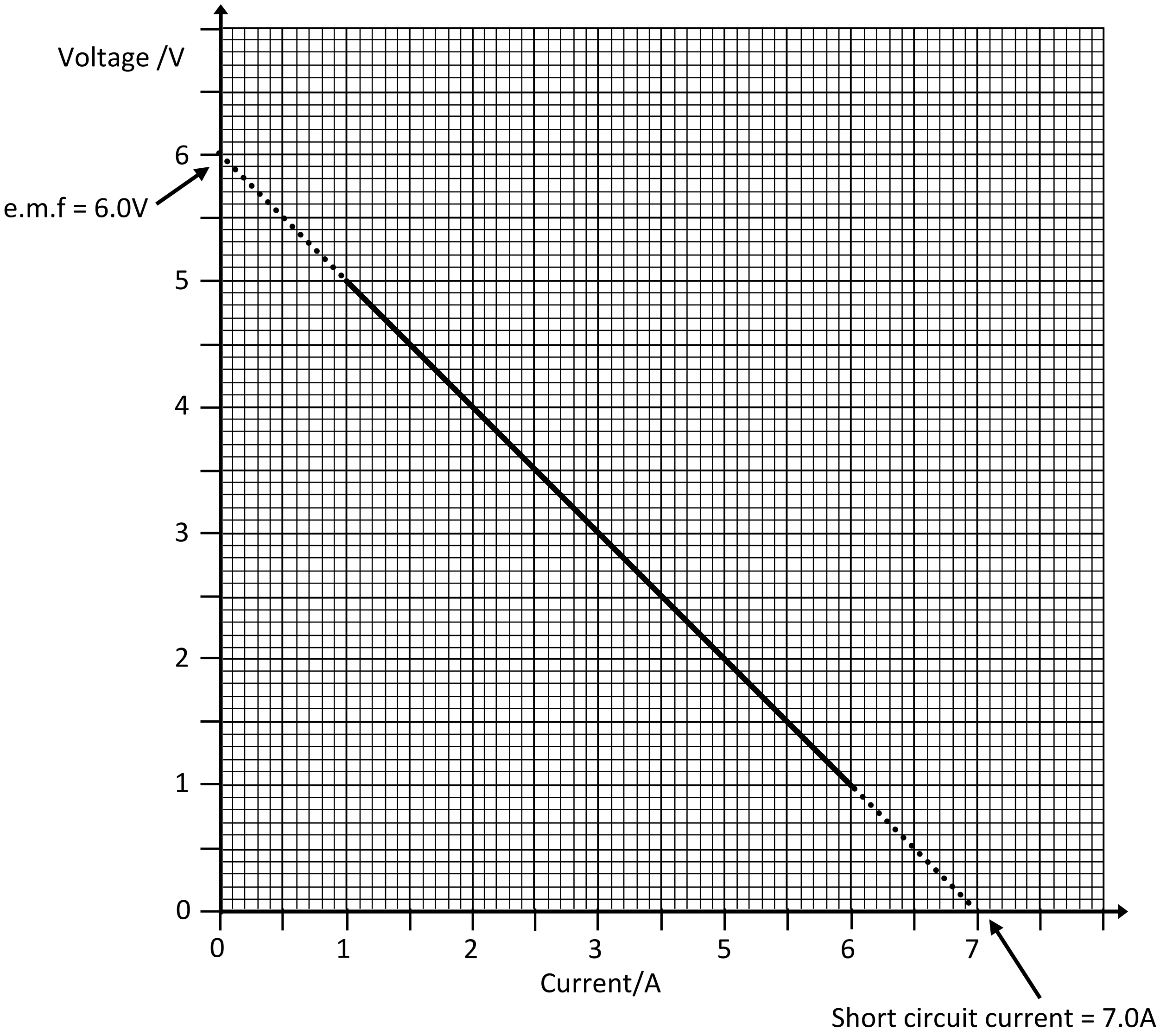
a. The e.m.f. of the battery.
b. The current reading if R was set to zero.
c. The internal resistance of the battery.





Solution

Extend the graph line until it meets the voltage and current axes.



a. E.m.f is 6.0V

b. When R is zero the battery is short circuited. I = 7.0A.

c. Internal resistance is the negative of the gradient of the graph.

$$r = -\frac{0 - 6.0}{7.0 - 0} = 0.86\Omega$$

Problem book page 15 to 18 questions 14 to 17.

Homework Internal Resistance

Key Area: Capacitors

Previous Knowledge

Electrical charges

$Q = It$

Symbols used in electrical circuit drawings

Success Criteria

4.1 I can describe a capacitor.

4.2 I can define capacitance.

4.3 I can use an appropriate relationship to solve problems involving capacitance, charge and potential difference.

4.4 I know that the total energy stored in a capacitor is the area under the charge potential difference graph.

4.5 I can solve problems involving energy, charge, capacitance and potential difference.

4.6 I can state the potential difference across an uncharged capacitor and a fully charged capacitor in a circuit.

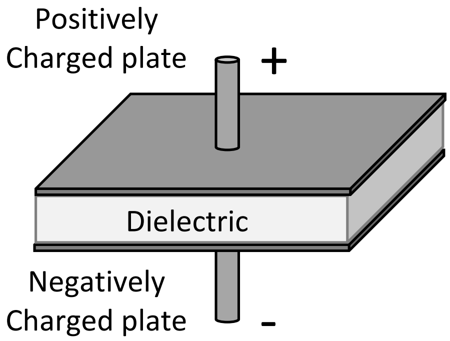
4.7 I can use Ohm's Law to calculate the initial charging current in a circuit containing a resistor and capacitor.

4.8 I am aware of the variation of current and potential difference with time for both charging and discharging cycles of a capacitor in a CR circuit.

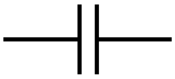
4.9 I am aware of the effect of resistance and capacitance on charging and discharging curves in a CR circuit.

4.1 I can describe a capacitor.

A capacitor is an electronic device which stores electrical energy. It usually consists of two electrical conductors (plates) separated by and insulating layer (dielectric). When a potential difference is applied across the capacitor electrons are transferred to one plate making it negatively charged and electrons removed from the other plate making it positively charged. This allows energy to be stored in the electric field between the plates.



4.2 I can define capacitance


Capacitor symbol for electrical circuit drawings.

Capacitance is defined as

Charge (Coulombs, C)

Capacitance (Farad ,F)

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

Potential Difference (Volts, V)

4.3 I can use an appropriate relationship to solve problems involving capacitance, charge and potential difference.

<u>Example</u>
A 3.7V battery is connected across a 10pF capacitor. Find the charge stored in the capacitor when fully charged.

<u>Solution</u>

$C = 10\text{pF} = 10 \times 10^{-12}\text{F}$

$V = 3.7\text{V}$

$C = \frac{Q}{V} \quad \Rightarrow \quad Q = CV$

$Q = 10 \times 10^{-12} \times 3.7$

$Q = 3.7 \times 10^{-11}\text{C}$

Note
C is used for the **quantity** Capacitance with units of Farads, F.

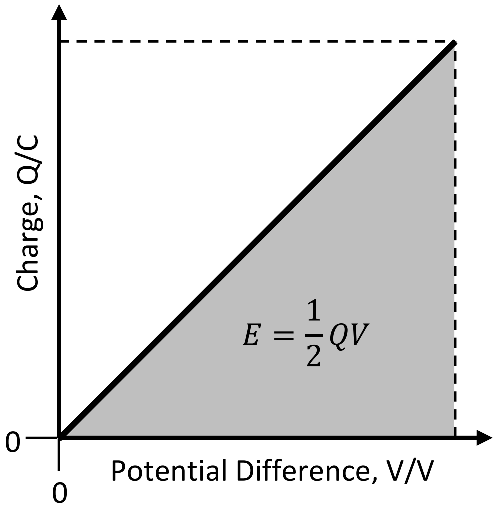
C is also used as the **units** of the quantity of Charge, *Q*.

Problem book page 19 questions 1 to 6, page 21 question 11

4.4 I know that the total energy stored in a capacitor is the area under the charge potential difference graph.

The energy stored in a capacitor is given by the area under the charge against potential difference graph.

As can be seen from the graph the energy is given by the area of the shaded triangle.



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

Also using the relationship

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

Gives

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

These relationships relate the energy stored in a capacitor to the charge, potential difference and capacitance. Knowing any two will allow the energy to be calculated.

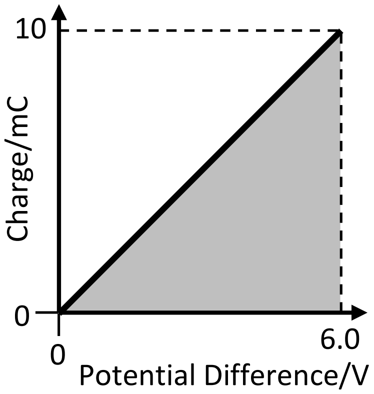
4.5 I can solve problems involving energy, charge, capacitance and potential difference.

The relationships below allow the solution of problems involving the energy stored in a capacitor, charge, capacitance and potential difference.

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

<u>Example</u>

Using the graph shown find the energy stored in the capacitor when it is fully charged.



<u>Solution</u>

From the graph

$$Q = 10\text{mC} = 10 \times 10^{-3}\text{C}$$

$$V = 6.0\text{V}$$

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

$$E = \frac{1}{2} \times 10 \times 10^{-3} \times 6.0$$

$$E = 0.030\text{J}$$

Example
A 10pF capacitor is charged using a 6.0V supply. Calculate the energy stored in the capacitor.

Solution
$C = 10\text{pF} = 10 \times 10^{-12}\text{F}$
$V = 6.0\text{V}$

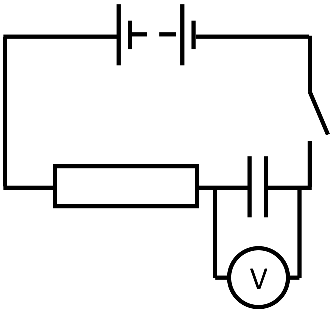
$$E = \frac{1}{2}CV^2$$

$$E = \frac{1}{2} \times 10 \times 10^{-12} \times 6.0^2$$

$$E = 1.8 \times 10^{-10}\text{J}$$

Problem book page 20 questions 7 and 8.

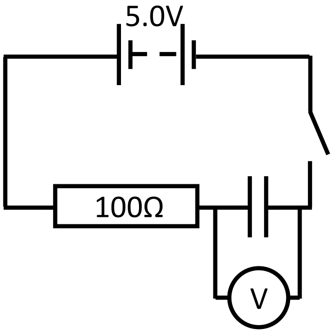
4.6 I can state the potential difference across an uncharged capacitor and a fully charged capacitor in a circuit containing a resistor and a capacitor.



In the circuit shown

- When a capacitor is discharged there is zero potential difference across the capacitor.
- When the switched is first closed the potential difference across the capacitor will be zero.
- Since the capacitor and resistor are in series the voltage across each must sum to the supply voltage.
- As the capacitor charges the potential difference across the capacitor increases and the potential difference across the resistor decreases.
- When fully charged the potential difference across the capacitor will be the same as the supply voltage. There will be zero potential difference across the resistor.

4.7 I can use Ohm's Law to calculate the initial charging current in a circuit containing a resistor and capacitor.



Example
In the circuit shown find the initial current in the circuit when the switch is closed.

Solution
When the switch is first closed there is zero potential difference across the capacitor and so 5.0V across the 100Ω resistor.

$$V = IR$$

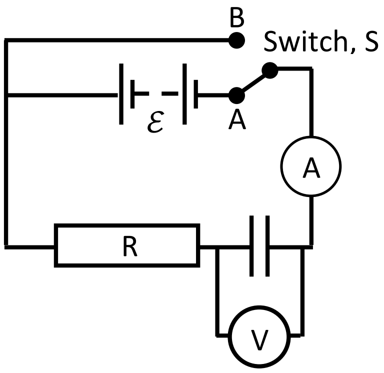
$$I = \frac{V}{R}$$

$$I = \frac{5.0}{100}$$

$$I = 0.05\text{A}$$

Problem book page 20 questions 9 and 10

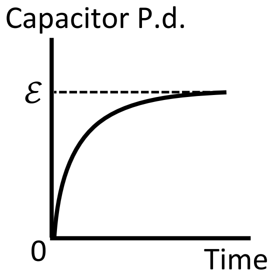
4.8 I am aware of the variation of current and potential difference with time for both charging and discharging cycles of a capacitor in a CR circuit.

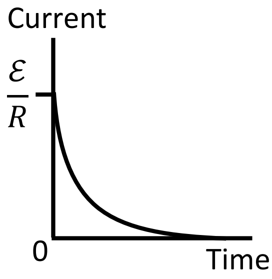


In the circuit shown when switch S is moved to position A the capacitor charges. When moved to position B the capacitor discharges.

The graphs of potential difference across the capacitor against time and current against time are shown below.

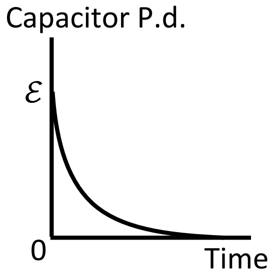
Charging

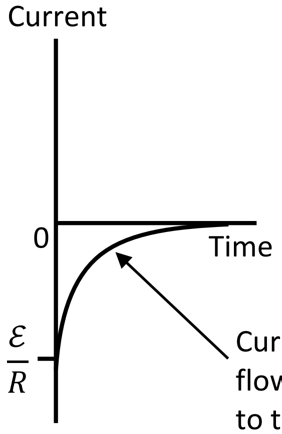




Switch in position A. The capacitor is charging.
The voltage rises from zero until it reaches the e.m.f. of the battery, $\mathcal{E}$.
The current has an initial value of $\frac{\mathcal{E}}{R}$ which falls towards zero.

Discharging





Current is negative as it is flowing in the opposite direction to the charging current.

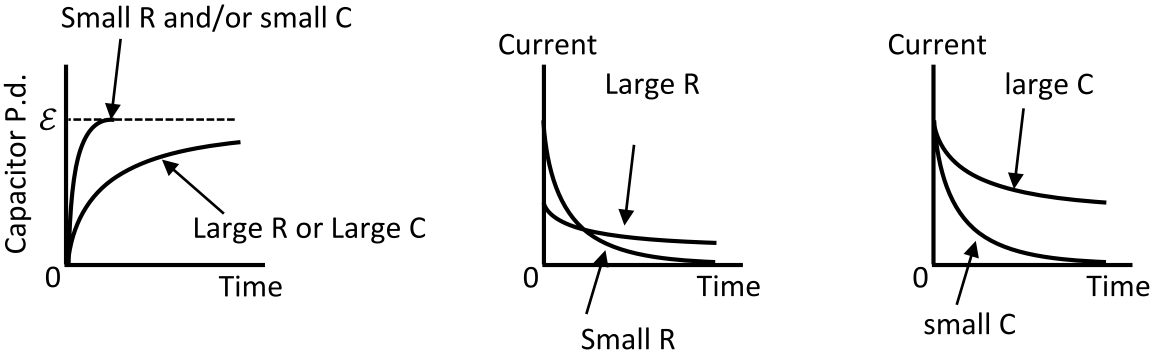
Switch in position B. The capacitor is discharging.
The voltage falls towards zero from an initial value of $\mathcal{E}$.
The current has an initial value of $\frac{\mathcal{E}}{R}$ which falls towards zero.

Problem book pages 22 to 24 questions 12 to 15

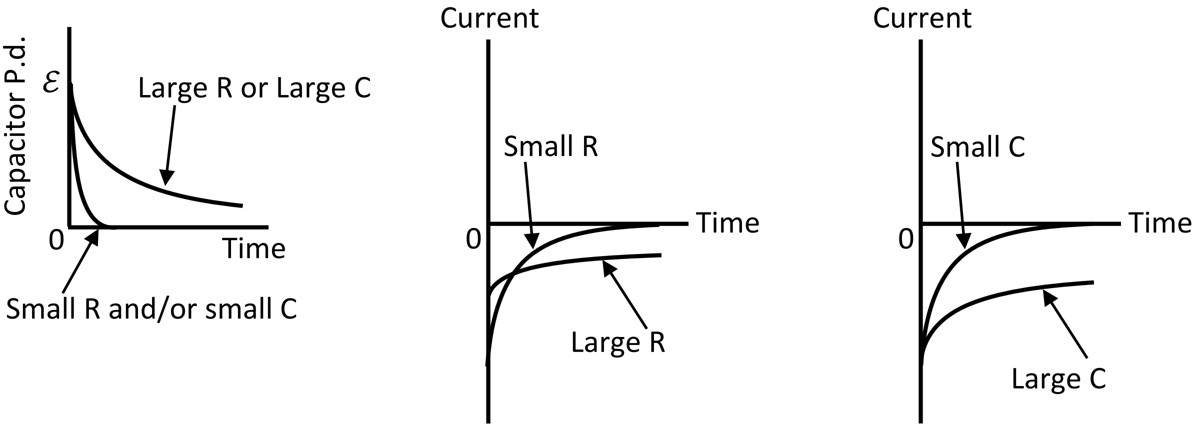
4.9 I am aware of the effect of resistance and capacitance on charging and discharging curves in a CR circuit.

Having a large resistance in the circuit reduces the charging rate of the capacitor so it takes a longer time to charge and discharge.
A larger value of capacitance also means the capacitor takes longer takes a longer time to charge and discharge.

Charging graphs for different values of resistance (R) and capacitance (C).



Discharging graphs for different values of resistance (R) and capacitance (C).



Problem book pages 24 and 26 questions 16 to 17

Homework Capacitance

Key Area: Conductors, Semiconductors and Insulators

Previous Knowledge

Electrical charges
Energy Levels

Success Criteria

5.1 I can categorise solids into conductors, semiconductors and insulators by their ability to conduct electricity.

5.2 I can explain the electrical properties of conductors, insulators and semi-conductors using the electron population of the *conduction band, the valence band and the energy difference* between them.

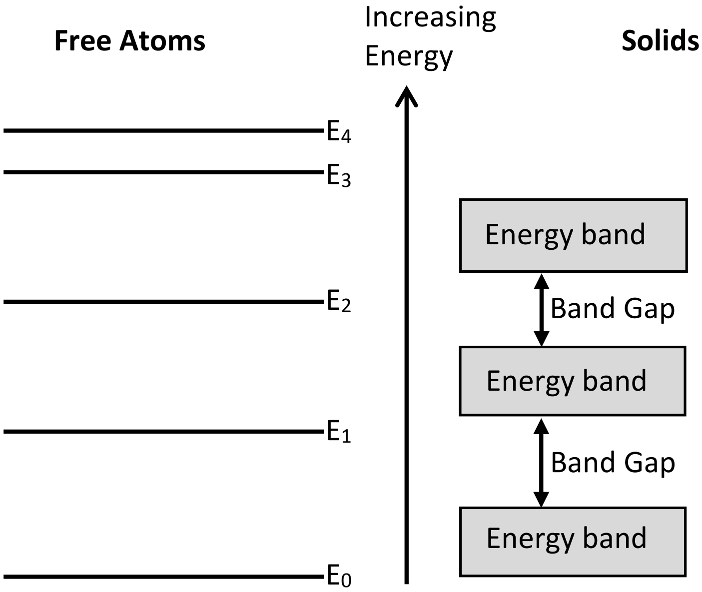
5.1 I can categorise solids into conductors, semiconductor and insulators by their ability to conduct electricity.

Solids can be categorised into three groups: conductors, semiconductors and insulators based on their ability to conduct electricity:

- Conductors allow an electric current to be conducted. Their electrical resistance is very low.
- Insulators do not allow an electric current to be conducted. Their electrical resistance is very high.
- Semi-conductors allow some electric current to be conducted. Their electrical resistance is high.

To understand why some materials are better conductors than others we need to look at the arrangement of electrons in atoms.

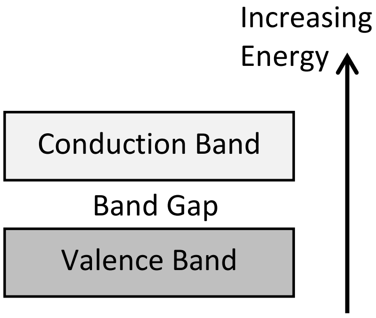
5.2 I can explain the electrical properties of conductors, insulators and semi-conductors using the electron population of the *conduction band, the valence band and the energy difference* between them.



In free atoms e.g in low pressure gases, electrons are contained in discrete energy levels. Electrons can only have energies given by the permitted energy levels E_0, E_1, E_2 etc. Electrons cannot have an energy other than the energies given by the energy levels.

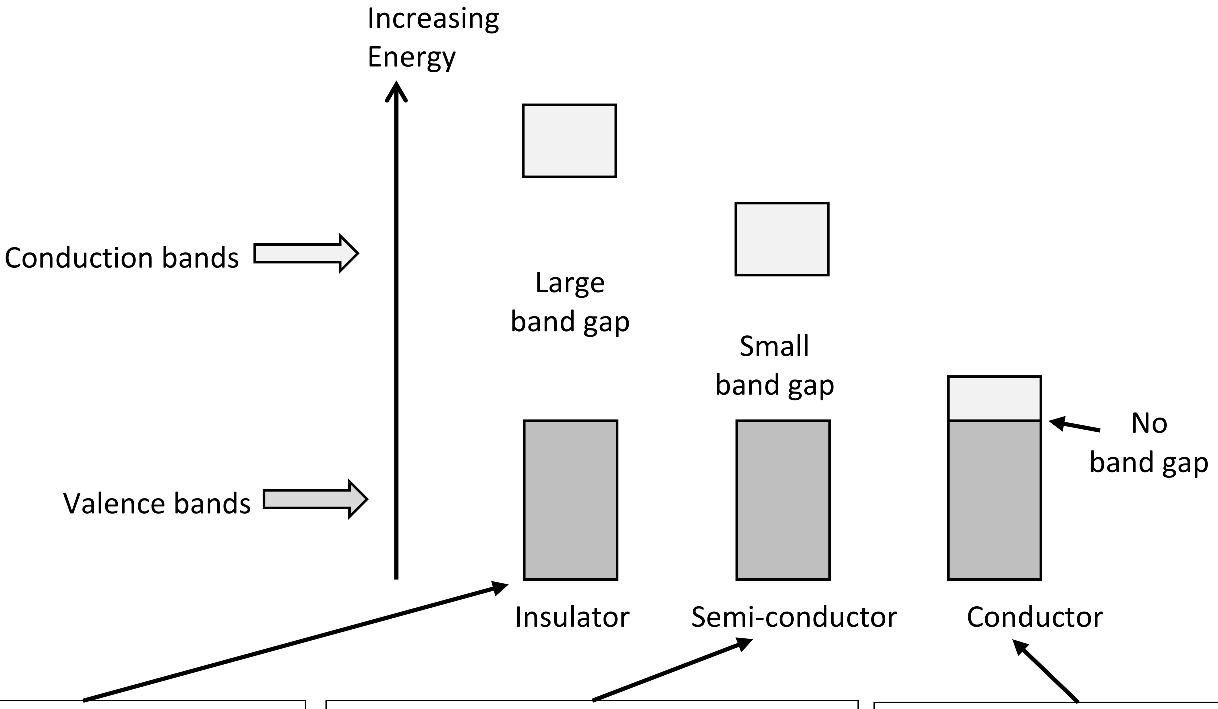
When the atoms form solids, the electrons become contained in continuous energy bands separated by gaps. Electrons can only have energies within the range of the energy bands. Electrons cannot have energies corresponding to the energies in the band gaps.

There can be several energy bands in a material. Usually it is only the top two bands which are involved in conduction. These bands are called the conduction band and the valence band.



For conduction to occur a material it must have electrons in its conducton band or the valence band must have spaces for the electrons to move into.

The diagram below shows the arrangements of the conduction band and valence bands in insulators, semi-conductors and insulators.



In an **insulator** all available energy levels in the valence band are filled.
The conduction band is empty so no conduction takes place.
There is a large band gap between the valence and conduction bands. When a potential difference is applied electrons do not have enough energy to cross this band gap to enter the conduction band.

In a **semiconductor** at low temperatures all available energy levels in the valence band are filled and the conduction band is empty so no conduction takes place.
At higher temperatures thermal motion of the atoms can give electrons sufficient energy to cross the small band gap into the conduction band.
This means that the conduction band has some electrons available for conduction when a potential difference is applied.
This also leaves gaps in the valence band allowing conduction.

In a **conductor** the valence band and conduction bands are continuous. There is no band gap. There are many energy levels available for the electrons to move into so conduction will take place when a potential difference is applied.

Problem book page 27 question 1

Key Area: P-N Junctions

Previous Knowledge

Electrical charges
Energy Levels
Semiconductor conduction

Success Criteria

6.1 I understand what is meant by the term conductivity.

6.2 I know that the conductivity of semiconductors can be controlled, resulting in two types: p-type and n-type.

6.3 I know that the addition of an atom of valency five into and extrinsic semiconductor produces an n-type semiconductor.

6.4 I know that the addition of an atom of valency three into an extrinsic semiconductor produces a p-type semiconductor.

6.5 I know that when a p-type and an n-type semiconductor are joined, a depletion layer with an electric field across it is formed at the p-n junction.

6.6 I understand the terms *forward bias* and *reverse bias*.

6.7 I know that an LEDs is forward biased p-n junction which emits photons when electrons “fall” from the conduction band into the valence band.

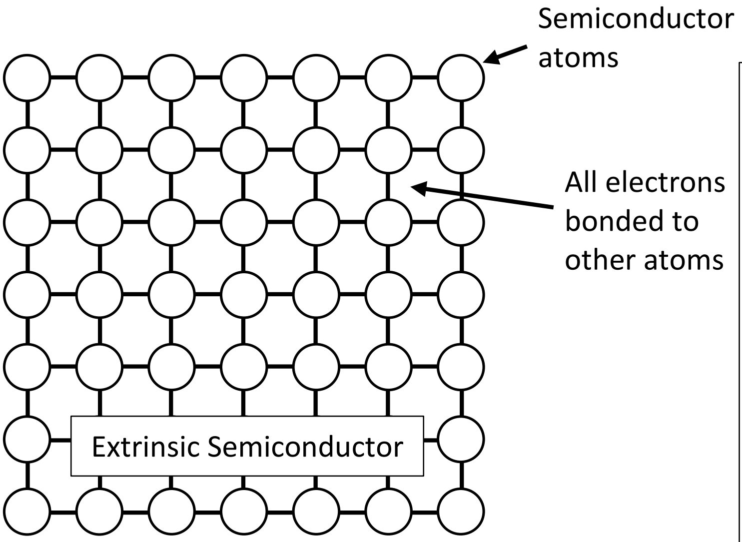
6.8 I know that solar cells are p-n junctions designed so that a potential difference is produced when photons enter the depletion layer.

6.1 I understand what is meant by the term conductivity.

Conductivity is a measure of how easily a material will allow current to pass. It is the inverse of resistance.

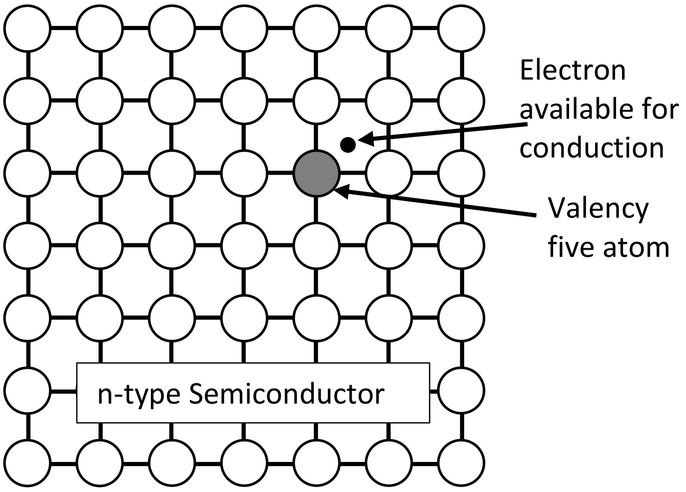
Low conductivity – High resistance
High conductivity – Low resistance.

6.2 I know that the conductivity of semiconductors can be controlled, resulting in two types: p-type and n-type.



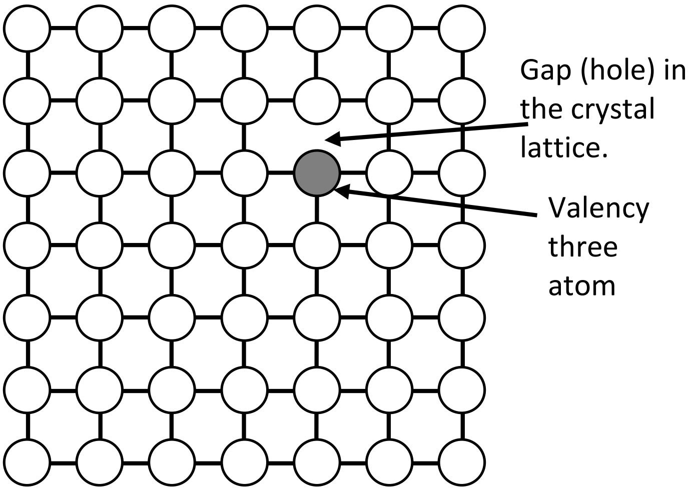
An extrinsic semiconductor has a valency of four so there are four electrons available to form bonds with other semiconductor atoms. All electrons are paired to electrons in other atoms producing a filled valence band.
As there are no electrons in the conduction band of an extrinsic semiconductor it will not conduct.
The addition of small quantities of other atoms (doping) can change the availability of electrons in the valence and conduction bands allowing conduction. There are two types doped semiconductors known as an n-type and p-type.

6.3 I know that the addition of an atom of valency five into an extrinsic semiconductor produces an n-type semiconductor.



An n-type semiconductor is produced when small quantities of atoms with a valency of five are added to the crystal lattice. Four of the valence electrons form bonds with other atoms leaving the fifth in the conduction band which allows conduction to occur. Adding these elements is called doping. Examples of valency five doping atoms are antimony, arsenic and phosphorus.
Electrons are the majority charge carriers in n-type semiconductors as they carry most of the current.

6.4 I know that the addition of an atom of valency three into an extrinsic semiconductor produces a p-type semiconductor.

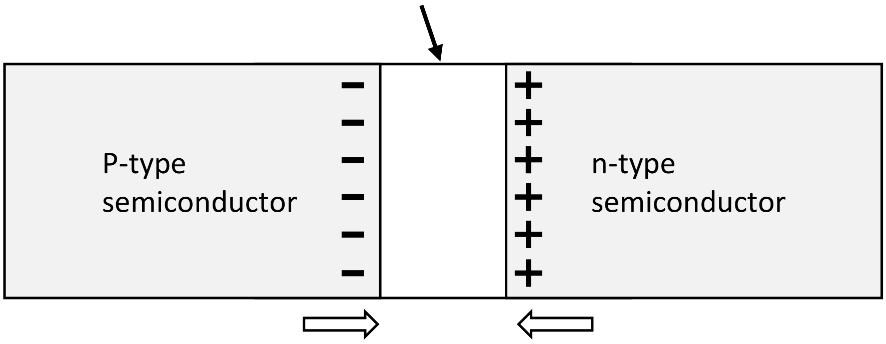


A P-type semiconductor is produced when small quantities of atoms with a valency of three are added to the crystal lattice. The three valence electrons form bonds with other atoms. As four electron are required to complete the bonds and only three are available a “hole” is left in the crystal lattice and in the valence band. This allows other electrons to move into the hole allowing conduction. Examples the valence three doping atoms are boron, aluminium and gallium.
Holes are the majority charge carriers in p-type semiconductors as they carry most of the current.

Problem book page 28 questions 2 to 4

6.5 I know that when a p-type and an n-type semiconductor are joined, a depletion layer with an electric field across it is formed at the p-n junction.

Depletion layer which has no electrons or holes available for conduction



Holes move from the p-type semiconductor and combine with the electrons from the n-type semiconductor. This leaves the p-type semiconductor with a negative charge.

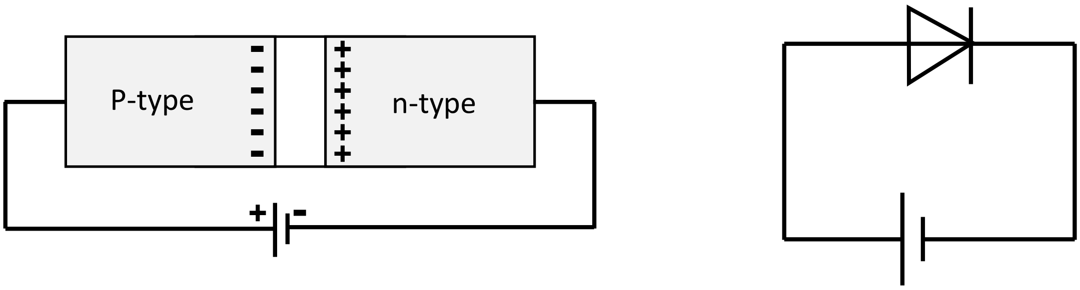
Electrons move from the n-type semiconductor and combine with holes from the p-type semiconductor. This leaves the n-type semiconductor with a positive charge.

The electric field is produced across the depletion due to the separation of charges. No electrons and holes are added or taken away. Charges are solely moving within the p-type and n-type semiconductors so the overall charge of a p-n junction is zero.

6.6 I understand the terms forward bias and reverse bias.

Forward Bias

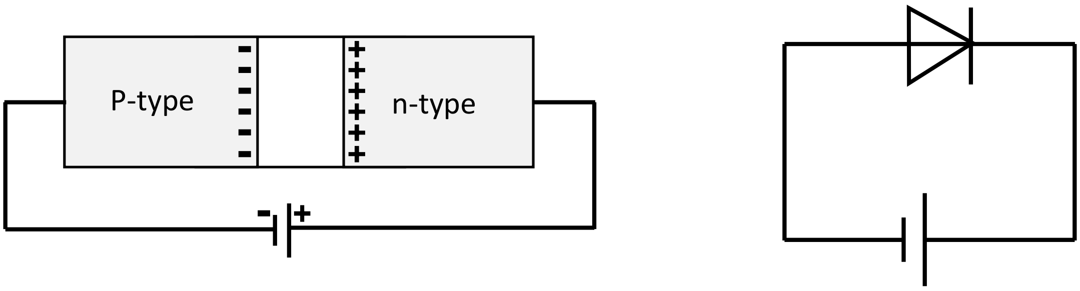
A p-n junction is forward biased when the n-type semiconductor is connected to the negative terminal and the p-type semiconductor to the positive terminal of a power supply. Electrons in the n-type semiconductor will be repelled by the negative terminal and attracted by the positive terminal. They will move across the depletion layer if they have sufficient energy to overcome the positive and negative charges in the p and n type semiconductors. The voltage required to overcome this voltage barrier is typically 0.7V. This flow of electrons across the depletion layer allows the diode to conduct.



Forward biased p-n junction diode

Reverse Bias

A p-n junction is reversed biased when the p-type semiconductor is connected to the negative terminal and the n-type semiconductor to the positive terminal of a power supply. Electrons in the n-type semiconductor will be repelled by the negative terminal and attracted by the positive terminal. They will move away from and widen the depletion layer. No electrons will flow across the depletion layer so the p-n junction will not conduct.

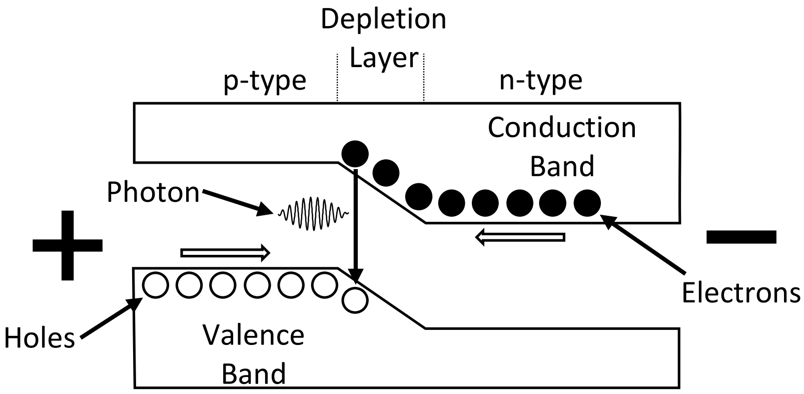


Reversed biased p-n junction diode

6.7 I know that an LEDs is forward biased p-n junction which emits photons when electrons “fall” from the conduction band into the valence band.

In a forward biased p-n junction

- Electrons in the conduction band of the n-type semiconductor move into the depletion layer.
- Holes in the valence band of the p-type material move into the depletion layer.
- The electrons “fall” from the higher energy conduction band and combine with the holes in the lower energy valence band.
- The energy released is emitted in the form of a photon.

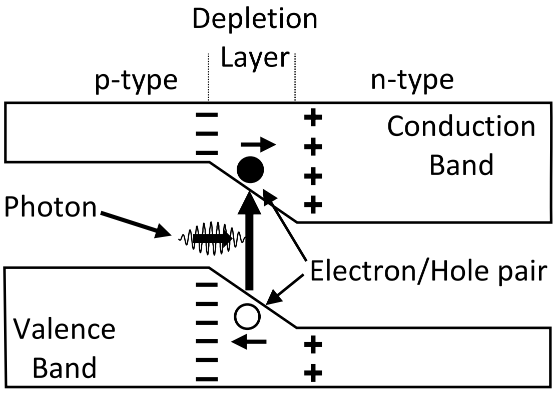


Forward biased p-n junction

Most semiconductor materials are opaque so photons cannot escape from the material. In LEDs the depletion layer is arranged so that it is very close to the surface allowing the photons to escape.

Problem book pages 28 questions 5 and 6, page 29 question Q7a, Q7c

6.8 I know that solar (photovoltaic) cells are p-n junctions designed so that a potential difference is produced when photons enter the depletion layer.



A photovoltaic cell consists of a p-n junction where the depletion layer lies close to the surface of the semiconductor. When photons enter the depletion layer the energy of each photon is absorbed by an electron. This gives the electron sufficient energy to move from the valence to the conduction band leaving a hole in the valence band. The electric field across the p-n junction (see section 6.4) moves the electron into the n-type material and the hole into the p-type material. This separation of charges creates a potential difference across the p-n junction.

Problem book 29 and 30 questions 9b and 10

Homework Conductors, Semiconductors and Insulators.

Quantities, Units and Multiplication Factors

Quantity	**Quantity Symbol**	**Unit**	**Unit Abbreviation**
Current	*I*	Ampere	A
Voltage	*V*	Volt	V
Resistance	*R, r*	Ohm	Ω
Capacitance	*C*	Farad	F
Frequency	*F*	Hertz	Hz
Period	*T*	Second	S
Charge	*Q*	Coulomb	C
Power	*P*	Watt	W
e.m.f	$\mathcal{E}$	Volt	V
t.p.d.	*V*	Volt	V
Planck's Constant	h	Joule second	Js

Prefix Name	Prefix Symbol	Multiplication Factor
Pico	p	$\times 10^{-12}$
Nano	n	$\times 10^{-9}$
Micro	µ	$\times 10^{-6}$
Milli	m	$\times 10^{-3}$
Kilo	k	$\times 10^{3}$
Mega	M	$\times 10^{6}$
Giga	G	$\times 10^{9}$
Tera	T	$\times 10^{12}$

Relationships required for Physics Higher

$d = \bar{v}t$

$s = \bar{v}t$

$v = u + at$

$s = ut + \frac{1}{2}at^2$

$v^2 = u^2 + 2as$

$s = \frac{1}{2}(u+v)t$

$W = mg$

$F = ma$

$E_W = Fd$

$E_p = mgh$

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

$P = \frac{E}{t}$

$p = mv$

$Ft = mv - mu$

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

$t' = \frac{t}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$

$l' = l\sqrt{1-\left(\frac{v}{c}\right)^2}$

$f_o = f_s\left(\frac{v}{v \pm v_s}\right)$

$z = \frac{\lambda_{observed} - \lambda_{rest}}{\lambda_{rest}}$

$z = \frac{v}{c}$

$v = H_0 d$

$W = QV$

$E = mc^2$

$E = hf$

$E_k = hf - hf_0$

$E_2 - E_1 = hf$

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

$v = f\lambda$

$d\sin\theta = m\lambda$

$n = \frac{\sin\theta_1}{\sin\theta_2}$

$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2}$

$\sin\theta_c = \frac{1}{n}$

$I = \frac{k}{d^2}$

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

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

$I_{peak} = \sqrt{2}I_{rms}$

$Q = It$

$V = IR$

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

$R_T = R_1 + R_2 + \ldots.$

$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots.$

$E = V + Ir$

$V_1 = \left(\frac{R_1}{R_1 + R_2}\right)V_s$

$\frac{V_1}{V_2} = \frac{R_1}{R_2}$

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

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

path difference $= m\lambda$ or $\left(m + \frac{1}{2}\right)\lambda$ where $m = 0, 1, 2 \ldots$

random uncertainty $= \frac{\text{max. value} - \text{min. value}}{\text{number of values}}$

DATA SHEET

COMMON PHYSICAL QUANTITIES

Quantity	*Symbol*	*Value*	*Quantity*	*Symbol*	*Value*
Speed of light in vacuum	c	3·00 × 10^{8} m s^{-1}	Planck's constant	h	6·63 × 10^{-34} J s
Magnitude of the charge on an electron	e	1·60 × 10^{-19} C	Mass of electron	m_e	9·11 × 10^{-31} kg
Universal Constant of Gravitation	G	6·67 × 10^{-11} m^{3} kg^{-1} s^{-2}	Mass of neutron	m_n	1·675 × 10^{-27} kg
Gravitational acceleration on Earth	g	9·8 m s^{-2}	Mass of proton	m_p	1·673 × 10^{-27} kg
Hubble's constant	H_0	2·3 × 10^{-18} s^{-1}			

REFRACTIVE INDICES

The refractive indices refer to sodium light of wavelength 589 nm and to substances at a temperature of 273 K.

Substance	*Refractive index*	*Substance*	*Refractive index*
Diamond	2·42	Water	1·33
Crown glass	1·50	Air	1·00

SPECTRAL LINES

<table>
<tr><th><i>Element</i></th><th><i>Wavelength</i>/nm</th><th><i>Colour</i></th><th><i>Element</i></th><th><i>Wavelength</i>/nm</th><th><i>Colour</i></th></tr>
<tr><td>Hydrogen</td><td>656</td><td>Red</td><td>Cadmium</td><td>644</td><td>Red</td></tr>
<tr><td></td><td>486</td><td>Blue-green</td><td></td><td>509</td><td>Green</td></tr>
<tr><td></td><td>434</td><td>Blue-violet</td><td></td><td>480</td><td>Blue</td></tr>
<tr><td></td><td>410</td><td>Violet</td><td colspan="3">Lasers</td></tr>
<tr><td></td><td>397</td><td>Ultraviolet</td><td><i>Element</i></td><td><i>Wavelength</i>/nm</td><td><i>Colour</i></td></tr>
<tr><td></td><td>389</td><td>Ultraviolet</td><td>Carbon dioxide</td><td>9550
10590</td><td>Infrared</td></tr>
<tr><td>Sodium</td><td>589</td><td>Yellow</td><td>Helium-neon</td><td>633</td><td>Red</td></tr>
</table>

PROPERTIES OF SELECTED MATERIALS

Substance	*Density*/kg m^{-3}	*Melting Point*/K	*Boiling Point*/K
Aluminium	2·70 × 10^{3}	933	2623
Copper	8·96 × 10^{3}	1357	2853
Ice	9·20 × 10^{2}	273	. . . .
Sea Water	1·02 × 10^{3}	264	377
Water	1·00 × 10^{3}	273	373
Air	1·29	. . . .	. . . .
Hydrogen	9·0 × 10^{-2}	14	20

The gas densities refer to a temperature of 273 K and a pressure of 1·01 × 10^{5} Pa.