Higher Physics – Electricity

Summary Notes

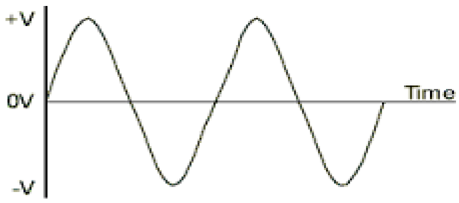
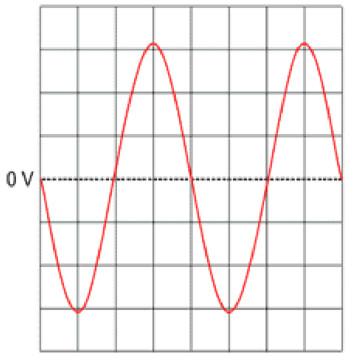
Contents

In the next few pages there will be tables with knowledge that **<u>must</u>** be learned before the Higher Physics exam. The wording used is what is acceptable when answering questions in the exam, although at times there will be alternative answers. In the 1st box put a ✓ or ✗ to show your understanding. You can use the 2nd box to check your understanding at a later date.

Using this sheet **<u>will</u>** help you become more prepared for your final exam, however it is down to you to put in the hard work to learn as much as possible to achieve your best.

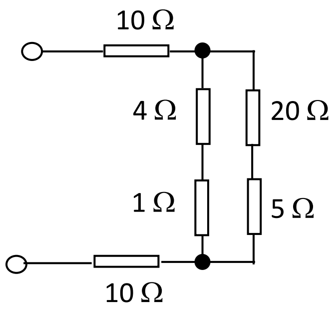
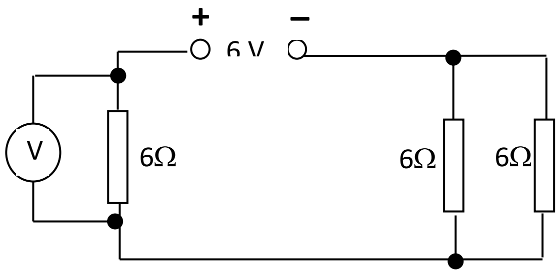
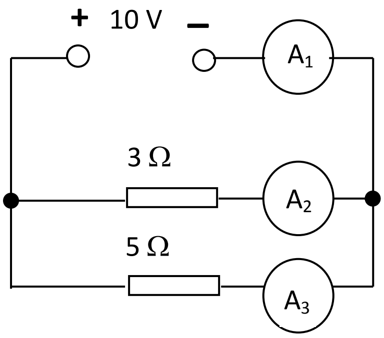
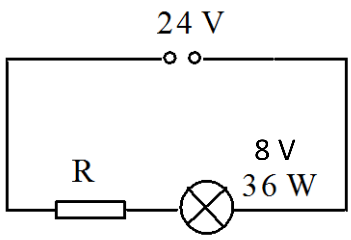
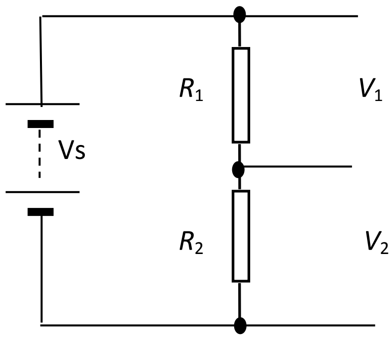
Use the extra space sections to include any additional information that you find when doing past paper questions/reading your notes etc…

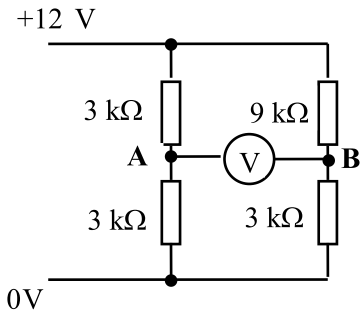
Section 1 – Monitoring and measuring a.c.

A d.c. (direct current) supply has one size and one direction.		
An a.c. (alternating current) supply is a current which changes direction and instantaneous value with time. This is shown as a sine wave on an oscilloscope screen. Time is measured using the x-axis and voltage is measured using the y-axis. 		
The frequency of the a.c. supply is found from the x-axis (timebase) using these steps; (timebase = 2 ms) 1. find the number of boxes for one complete wave. (**<u>4 boxes</u>**) 2. find the period by multiplying the number of boxes by the timebase. ($T = 4 \times 2\times10^{-3}$ = **<u>0.008s</u>**) 3. Use the equation ***f* = 1/T** to find the frequency. (*f* = 1/T *f* = 1/0.008 ***<u>f</u>* <u>= 125 Hz</u>**) 		
The peak voltage of an a.c. supply is found by counting the number of boxes which equal the amplitude of the wave. This is from the centre to the top or bottom of the wave. The number of boxes is then multiplied by the y-gain or voltage gain value. This answer is called the peak voltage. (If the above a.c. trace had a y-gain setting of 2 V per division the peak voltage would be; $V_p = 3 \times 2$ = **<u>6 V</u>**)		
The peak voltage only occurs twice for every wave. This is not a true reflection of the voltage the a.c. supply has. The true value of the voltage is taken as the average voltage for one whole wave. This is called the r.m.s. voltage (V_{rms}). The r.m.s. Voltage is the voltage that is quoted by a voltmeter. Mains r.m.s. voltage is 230 Volts while the peak voltage is 325 Volts.		
The r.m.s. voltage and peak voltage are linked by the equation; $$V_{peak} = \sqrt{2}\ V_{rms}$$		
The r.m.s. current and peak current are linked by the equation: $$I_{peak} = \sqrt{2}\ I_{rms}$$		
When doing a calculation **<u>ALWAYS</u>** use r.m.s. values. If peak values are used in a calculation the answer will be wrong! For example; If I_{peak} = 2 A and Power = 8 W, calculate V_{rms}. You must find I_{rms} first then use the equation **P = IV** or the answer will be wrong. (Answer is **<u>V_{rms} = 5.7 V</u>**)		
Extra space for additional information		

Section 2 – Current, potential difference, resistance and power

Electrical current is the rate of flow of charge or the number of coulombs of charge passing a point each second.		
The relationship between charge and current is shown in the equation; **Q = It**		
Voltage is the energy given to each coulomb of charge.		
Potential difference is another name that is used instead of voltage. Potential difference is defined as the work done (energy) in moving one coulomb of charge between two points. It is more accurate to say the potential difference across a component rather than the voltage.		
The potential difference, current and resistance are linked in the equation; **V = IR** When describing you must say the potential difference is <u>**'across'**</u> the component and the current is <u>**'through'**</u> the component. If you mix these up you will not be awarded any marks for your descriptions, even if they are otherwise accurate. As the resistance increases in a circuit the current decreases.		
The power used by a component in a circuit is related to the potential difference, current and resistance using the following equations; $P = IV$ $P = I^2R$ $P = \frac{V^2}{R}$		
There are two types of circuits. Each of these circuits have rules for how the potential difference and current can be determined in the circuit.		
<u>In a series circuit;</u> The current is the same at all points. The supply voltage is shared across the components in the circuit. The total resistance is found by adding each individual resistance together.		
<u>In a parallel circuit;</u> The current is split up through each branch. Where you see a 'blob' in the circuit diagram the current will have to split up. The value of the supply voltage is the same as the potential difference across each branch. The total resistance is found by using the equation; $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$ where R_1 and R_2 are the resistance of each branch. You can go M.A.D. (multiply, add, divide) although this only works with two branches at a time. When a resistor is added in parallel with another resistor, the total resistance decreases. Also, if two resistors in parallel are the same value, the total resistance will be half the value of one of the resistors at the start.		
When using **V = IR** to determine a quantity it is important that the correct values are used. This can be tricky as some circuits have parallel and series sections in them. When finding the total resistance of a circuit always find the resistance of each branch first, then find the resistance of the parallel parts, then add any resistors that are in series.		

To find the total resistance solve; 1 – the total resistance of each branch (4 + 1 = 5 Ω and 5 + 20 = 25 Ω). 2 – the total resistance of the two branches in parallel (5 Ω and 25 Ω = 4.2 Ω). 3 – the total resistance for the circuit (4.2 + 10 + 10 = **24.2 Ω**). 		
To find the reading on the voltmeter; 1 – Find the total resistance. 2 – Use the total resistance and the supply voltage to find the supply current. **V = IR** 3 – Use the supply current and the resistance the voltmeter is across to find the voltmeter reading. **V = IR** (**V = 4 V**) can you get this answer? 		
To find the reading on the ammeters; To find the current through A_1 find the total resistance and then use **V = IR** with the supply voltage. To find the current through A_2 use **V = IR** with the supply voltage and resistance 3 Ω. To find the current through A_3 use **V = IR** with the supply voltage and resistance 5 Ω.  The reading on A_2 will be greater than A_3 as the resistance is less in this branch. The reading on A_1 will be equal to A_2 + A_3. (**A_1 = 5.33 A A_2 = 3.33 A A_3 = 2 A**)		
To find the power used in the resistor; 1 – Find the current through the lamp using **P = IV** 2 – Find the voltage across the resistor by subtracting the lamp voltage from the supply voltage. 3 – Use **P = IV** to get the power used by the resistor. (The answer is **P = 72 W**). 		
Potential divider circuits are series circuits which have two components. These components are usually resistors. The two equations that can be used in these circuits are; $\frac{V_1}{V_2} = \frac{R_1}{R_2}$ and $V_2 = \frac{R_2}{(R_1 + R_2)} V_s$ The equation V = IR can also be used in these questions. 		

You may also see two potential dividers joined together in parallel and be asked to find the voltage on the voltmeter (called the bridge voltage). To find this you need to find the voltage across V_2 for both potential dividers (see the previous diagram). The bridge voltage is the difference in the two voltage values you have calculated. (**<u>The bridge voltage here is 3 V</u>**). 		
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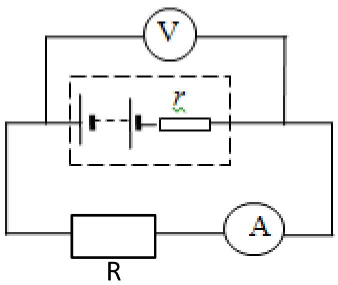
Section 3 – Electrical sources and internal resistance

The diagram shows a circuit which has internal resistance. The dashed box clearly shows that the battery has a small resistance when the switch is closed which is represented by a resistor. This is called the internal resistance and does not change unless stated that it does in the question. The current will be the same through the internal resistance and the lamp as it is a series circuit. 		
E.m.f. stands for electromotive force and is the voltage across the battery when **<u>no</u>** current is in the supply.		
The definition of e.m.f. is the energy given to each coulomb of charge that passes through the supply. You could also say it is the voltage across the battery when there is an open circuit (switch is open).		
T.p.d. stands for terminal potential difference. This is the voltage across the supply when there **<u>is</u>** a current in the supply (switch is closed). This voltage across the battery is the same as what would be across the load resistor (resistors outside the battery) in the circuit.		

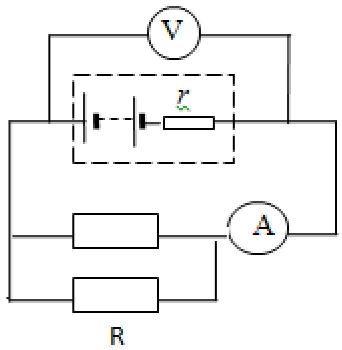
'Lost volts' is the difference between the e.m.f. and t.p.d. values. This occurs as the battery has a small internal resistance (inside the battery) and when a current passes through the battery a potential difference is generated across the internal resistance.

When solving questions with internal resistance the equation; **E = V + Ir** is given in the relationship sheet. It is easier at times to simply use; **V = IR** however you must be careful of which voltage and which resistance is used in the equation.

- If the e.m.f. is used then the total resistance must be used. $\mathbf{E = I\,(R + r)}$
- If it's the t.p.d. then the load resistance must be used. $\mathbf{V_{tpd} = IR}$
- If it's the lost volts then the internal resistance must be used. $\mathbf{V_{lv} = Ir}$

Remember that the current will always be the same as it is a series circuit, unless the load resistance or internal resistance is changed.

<u>Common exam Q</u>



A common way the load resistance can be altered is to add another resistor in parallel. This would **reduce** the reading on the voltmeter because;

- The load resistance decreases which decreases the total resistance in the circuit.
- The current in the circuit will increase.
- The lost volts across the internal resistance increases **OR** share of potential difference across the parallel branch decreases.

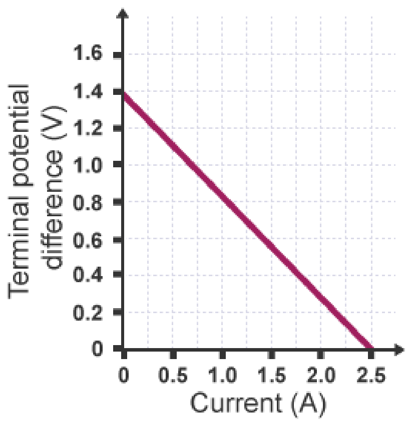
A short circuit is where a wire is placed across the terminals of the battery meaning the load resistance is no longer forming part of the circuit (R = 0). A short circuit will increase the current as there is less resistance. To find the current in the circuit the equation **E = I (R + r)** changes to **E = Ir**.

The final part of this section is using graphs to determine the e.m.f. and internal resistance.

<u>The e.m.f.</u> is found by determining the y-intercept (when the current is zero). (**<u>1.4 V</u>**)

<u>There are two ways to determine the internal resistance;</u>

1. The negative gradient of the line = internal resistance. (m = -0.56 so **<u>r = 0.56 Ω</u>**)
2. The equation **E = I r** where E is the y-intercept and I is the x-intercept (short circuit current).
   (E = I r 1.4 = 2.5 x r **<u>r = 0.56 Ω</u>**)



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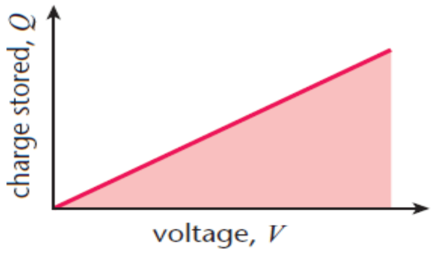
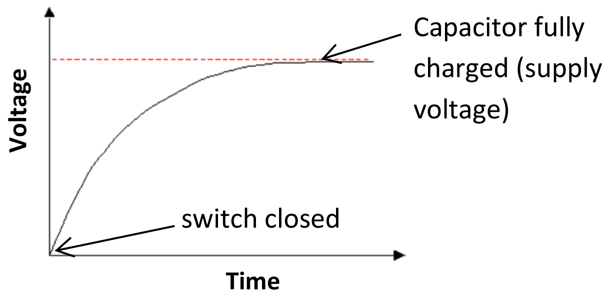
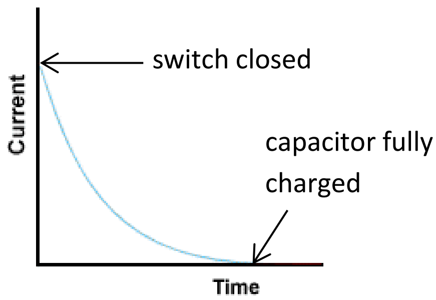
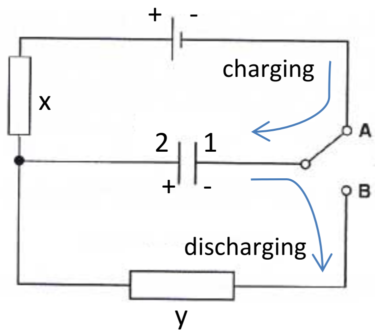
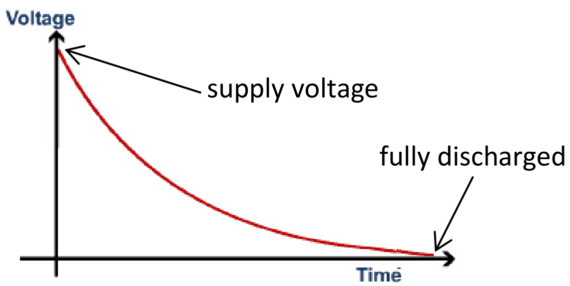
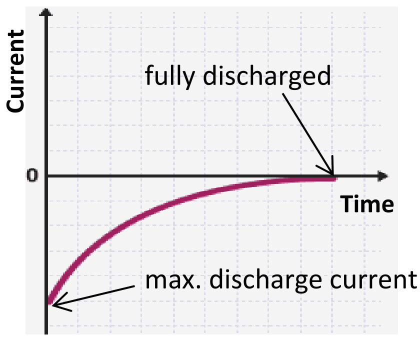
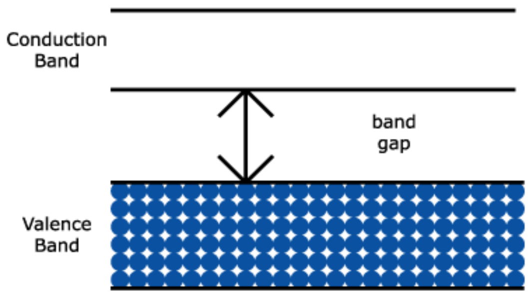
Section 4 – Capacitors

Capacitors are devices used to store charge. Each capacitor has a capacitance measured in Farads (F).		
Capacitance is the ratio of charge stored to potential difference. Capacitance is the gradient of the straight line in a charge against voltage graph and so is always a constant value. $\mathbf{C = \frac{Q}{V}}$		
If a capacitor of larger capacitance is used then the charge stored will be greater. The voltage across the capacitor can never be greater than the supply voltage.		
A capacitor has two plates which store charge. The plate which is connected to the negative side of the battery will be negatively charged as extra electrons are added to it. The plate connected to the positive side of the battery will be positively charged as electrons are removed from it. Electrons do not move across the gap between the plates.		
A capacitor will charge if it is connected to a battery. The capacitor stores energy during the charging process. This happens because work is done (energy) by the capacitor as negatively charged electrons experience a repelling force as they join the negatively charged plate. Work is done to overcome this repelling force.		
The energy stored by a capacitor is equal to the area under a charge against potential difference graph. Therefore $\mathbf{E = ½ Q V}$ There are two other equations to find the energy stored by a capacitor; $\mathbf{E = ½ C V^2}$ and $\mathbf{E = ½ Q^2 C}$ Any equation can be used to find the energy. 		
It is important to know what the question is asking in regards to energy. If it is the maximum energy then the supply voltage and maximum charge should be used. If it is the energy during the charging proccess then the voltage or charge stored at that point should be used.		
<u>When a capacitor is charging</u> there are two graphs we need to be familiar with. Also, we must recognise that just as the switch is closed the potential difference across the capacitor is zero and the current is at a maximum value. Once the switch is closed the potential difference across the capacitor increases and reaches a maximum value (the supply voltage) when the capacitor is fully charged. The current will decrease to zero when the capacitor is fully charged.  		

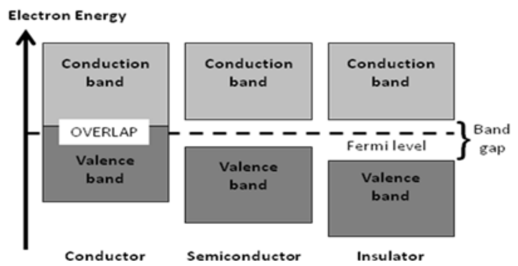
As a capacitor will be in a series circuit with a resistor, the potential difference across the resistor and capacitor will always equal the supply voltage. This means that the potential difference across the resistor will equal the supply voltage when the potential difference across the capacitor is zero. Also, the potential difference across the resistor will be zero when the capacitor is fully charged.		
The value of the resistance in the circuit will determine the maximum charging current. A greater resistance will result in a smaller maximum charging current.		
The maximum charging current is determined using the equation; **V = I R** The potential difference will be the supply voltage and the resistance value will be due to the resistor in the circuit.		
When the switch is in position A the capacitor is charging. Electrons leave the negative side of the cell or battery through point A to the capacitor plate (1). The size of the maximum charging current is determined by the resistance in the circuit. When the capacitor is charging this would be due to resistor (x). The capacitor charges as it is connected to a power supply. When the switch is changed to position B the electrons leave the plate (1) and go through point B to the positive plate (2). This means the current is in the opposite direction. The size of the maximum discharging current can be different from the charging current as it depends on the resistance of resistor (y). 		
There are also two graphs for a capacitor discharging. The potential difference across the capacitor will be equal to the supply voltage and then decrease to zero when the capacitor is fully discharged. As we saw from the previous diagram, the current will be in the opposite direction. This means the current is negative but the size of the maximum discharge current will be determined by the resistance in the circuit. The current will then decrease to zero when the capacitor is fully discharged.  		
As previously mentioned, the resistance in the circuit will affect the size of the maximum charging/discharging current. A greater resistance results in a lower current. A greater resistance will also result in a greater charging/discharging time as there will be less charge in the circuit if the current is lower (remember **Q = I t**). The potential difference across the capacitor when it is fully charged will not change.		

The capacitance of the capacitor will also affect the charging/discharging time. A greater capacitance will require more charge to be fully charged and so will take a greater time to charge. A smaller capacitance will therefore take less time. The size of the maximum charging/discharging current will not be affected and the size of the potential difference across the capacitor will also be unaffected.		
Extra space for additional information		

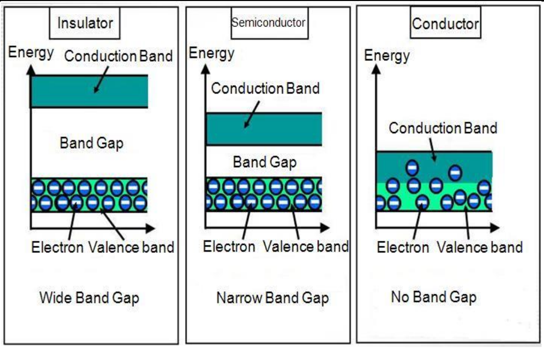
Section 5 – Conductors, semiconductors and insulators

Solids can be separated into three categories; conductors, semiconductors and insulators.		
In solids the atoms have energy levels or energy bands in which electrons are found.		
The band which is furthest from the nucleus and has a maximum number of electrons is called the valence band. The next furthest band from the nucleus (above the valence band) is called the conduction band. The space between each band is called the band gap. Electrons are not allowed here. 		
Conductors, semiconductors and insulators all have their valence band full of electrons but only conductors have 'free' electrons which are found in the conduction band. This means that conductors have a high conductivity (low resistance) while insulators have a low conductivity (high resistance). Semiconductors are a bit more complicated!!!		
In conductors the valence band and conduction band overlap. This allows the 'free' electrons to move from atom to atom in the conduction band when a potential difference is applied.		
In insulators the conduction band has no 'free' electrons. The band gap between the valence band and conduction band is very large and so electrons in the valence band cannot jump to the conduction band, even when a potential difference is applied.		

In pure (intrinsic) semiconductors the conduction band also has no 'free' electrons at low temperatures. However, the band gap from the valence band to the conduction band is small and so at higher temperatures (room temperature) a small number of electrons are able to jump from the valence band to the conduction band. This increases the conductivity of the semiconductor and therefore reduces its resistance.



The Fermi level is always between the valence band and conduction band.



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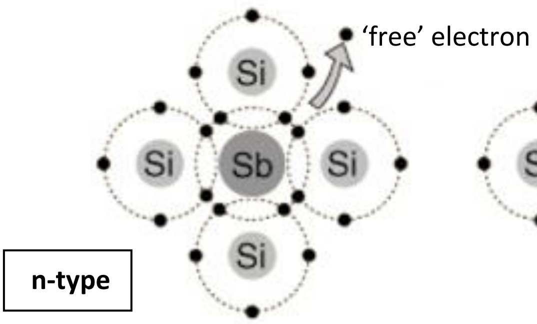
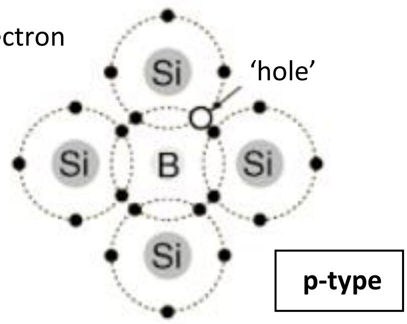
Section 6 – p-n junctions

The conductivity of a semiconductor can be increased by a process called doping. These are called extrinsic semiconductors.

Doping involves the addition of an impurity atom which has either; 5 outer electrons (n-type) or 3 outer electrons (p-type).

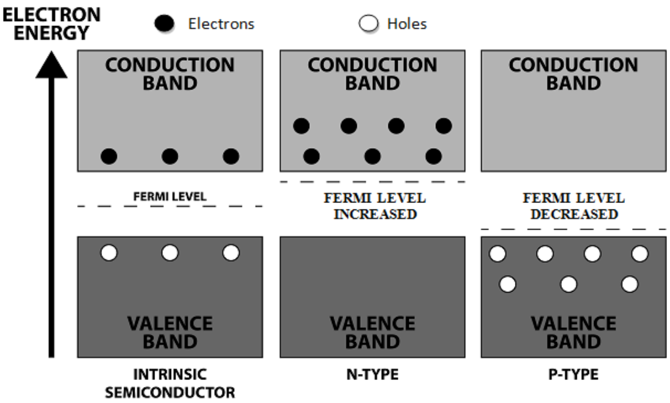




In a p-type semiconductor, because the impurity atom has 3 outer electrons there will be one electron missing which is called a 'hole'. Electrons will fill the hole which results in a movement of charge. This means the conductivity of the semiconductor has been increased.

In an n-type semiconductor, because the impurity atom has 5 outer electrons there will be one extra electron which is 'free' to move. This again results in a movement of charge meaning the conductivity of the semiconductor has increased.

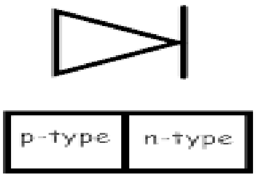
Both n-type and p-type semiconductors have **<u>neutral charge</u>**. The reason they are given the names n-type and p-type is to show that the nature of the charge that is free to move, a negative charge (electrons) or positive charge (holes).

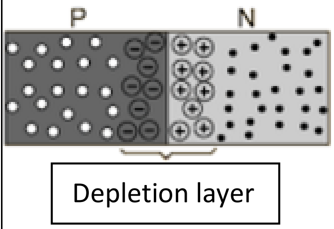


An intrinsic (pure) semiconductor will have 'free' electrons in the conduction band and 'holes' in the valence band. In the n-type semiconductor the 'free' electrons are found in the conduction band. In the p-type semiconductor the 'holes' are found in the valence band.

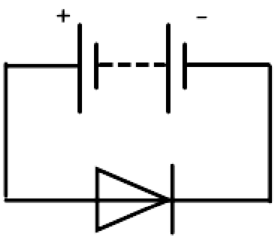
The fermi level is located where charge carriers ('free' electrons or 'holes' are likely to be). This is why the fermi level changes for n-type and p-type.

When a p-type semiconductor and n-type semiconductor are joined together a p-n junction is produced. Another name for a p-n junction is a diode. The n-type side of the diode is on the right in this diagram and the p-type side of the diode is on the left.

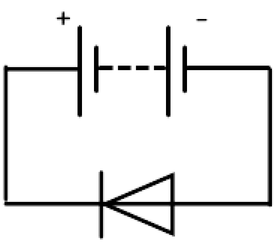




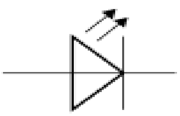
'Holes' from the p-type cross into the n-type while 'free' electrons from the n-type cross into the p-type. The 'free' electrons fill the 'holes' which creates a layer called the depletion layer. Charge cannot flow through the depletion layer unless the p-n junction is connected in the correct bias and the potential difference is large enough.



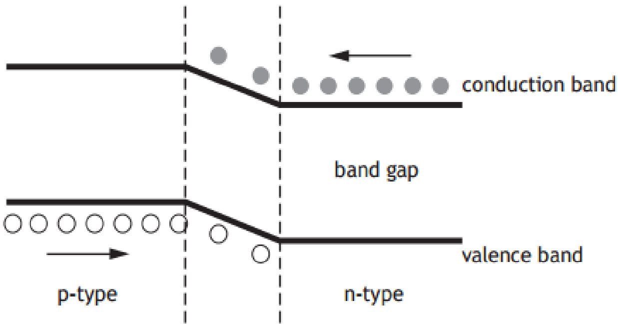
A p-n junction is connected in <u>forward bias</u> if the p-type is connected to the positive terminal of the battery and the n-type is connected to the negative terminal of the battery. The depletion layer is broken down if connected this way and charge can flow through the junction, if the potential difference is large enough.



A p-n junction is connected in <u>reverse bias</u> if the n-type is connected to the positive terminal of the battery and the p-type is connected to the negative terminal of the battery. When connected this way the depletion layer is widened and no charge can flow, even when a large potential difference is applied.



This is the symbol for an LED (light emitting diode). An LED is a p-n junction connected in forward bias which emits light (packets of waves called 'photons').

 Band theory is used to explain how they work. Electrons from the n-type conduction band move toward the p-type conduction band. When the electrons are in the p-n juncution they fall from the conduction band to the valence band where they pair with a 'hole'. A photon is then emitted. One electron that pairs with one 'hole' will emit one photon.		
The colour of light emitted by the LED can be predicted by determining the wavelenth of the photon. Visible light is between 700 and 400 nanometres (nm or x 10^{-9}m). Red is around 650 nm, Green around 520 nm and Blue around 480 nm. When asked only select one colour for the light emitted by an LED by examining what the wavelength of the light is. (Do not say a reddy, orangy, yellow colour!!! You will receive zero marks this type of answer).		
The wavelength of an LED is found using the equation; $\mathbf{v = f \lambda}$ The frequency is found using the equation; $\mathbf{E = h f}$ The energy of the photon is equal to the energy gap between the conduction band and valence band. **h** is planck's constant which is 6.63×10^{-34} Js.		
A solar cell is a p-n junction which produces a potential difference when photons enter the depletion layer. This is known as the photovoltaic effect.		
When a photon arrives at the depletion layer it causes electron-hole pairs to separate. The electron moves from the valence band to the conduction band while a hole will remain in the valence band. This means there will be a greater number of charge carriers and a potential difference is produced.		
The greater the number of photons that arrive at the depletion layer the greater the potential difference produced by the solar cell.		
Extra space for additional information		