Section 2

Physics

- Electricity
- Mechanics
- Nuclear Physics
- Waves

BMAT
CRASH COURSE

ELECTRICITY

Electricity is a topic that always comes up in every single BMAT paper without fail, and often has multiple questions associated with it. You should already know the basics of electricity from GCSE Physics (like circuit symbols etc), but there are some intricacies that you might not have covered (especially if you haven't done it at AS).

BASICS

Charge (Q) is measured in Coulombs (C). One electron has a charge of 1.6x10-19 C. 1 Coulomb is defined as the amount of charge that passes in 1 second when the current is 1 Ampere (though you probably don't need to know this).

Current (I) is the rate of flow of charge, and is measured in Amperes (A). A current of 1A means that 1 coulomb of charge flows past that point every second (hence the term "rate"). Therefore I=dQ/dt. Current is measured with Ammeters which are placed in series within a circuit – hence, they measure current at a specific point.

Potential Difference (Voltage, V) is measured in volts (V), and is the work done per unit charge. 1V means that 1 Joule of work is done in pushing 1 coulomb of charge through a particular area/component. Voltmeters are placed in parallel and have infinite resistance, so they measure current between 2 points in a circuit. We'll come back to the point about infinite resistance when discussing series and parallel circuits. V=W/Q

Resistance is difficult to define, but is measured in Ohms (Ω). Some people call it the ratio of voltage to current, which is a pretty obvious definition when you consider Ohm's Law (V=IR → R=V/I)

Power (P) is measured in watts (W) and is defined as the rate of transfer of energy. 1W is the transfer of 1 Joule of energy per second.

There are lots of formulae for power that you need to know:

$$E = ItV$$

(E = energy in Joules, I = current, t = time, V = voltage)

A note on units: Whenever you see a formula, the units will always be the SI units for that particular variable. So for example, energy is ALWAYS measured in Joules (not kilojoules or calories or anything else). Time is ALWAYS measured in seconds, not minutes or hours. You should therefore be very careful to convert times, energies, powers etc into the correct standard units before using them in any formulae.

The exception is where for example, power is given in KW and they want energy in KJ or something, but that only works because both values have the x1000 multiplier (kilo) associated with them.

$$P=IV$$

$$P = I^2R$$

$$P = V^2 / R$$

Armed with this information, we can answer the questions below.

Q - Which of the following is a correct unit of potential difference (voltage)?

A. Amp per Ohm
B. Coulomb per Joule
C. Joule per Second
D. Newton per Coulomb
E. Watt per Amp

A) Amp per ohm – that's current/resistance = I/R. We know from Ohm's Law (which has been hammered into our heads from a young age) that V = IR, so this can't be right.

B) Coulomb per joule – that's charge/energy. But we know from our definition of voltage that V = energy per unit charge.

C) Joule per second – this is the very definition of power, and therefore not voltage.

D) Newton per coulomb – Newton is a measure of force, and has practically nothing to do with electricity.

E) Watt per amp – That's power/current. We know that one of the formulae for power is $P= I^2R$,so $P/I=(I^2R)/I=IR=V$. This is therefore the right answer.

This was also a question from the specimen paper, and is a free mark:

Q - A resistor of resistance 1.5kΩ has a voltage of 30V applied across it. What is the current through it? (Give your answer in amperes.)

$$V = IR$$
$$I = V/R = 30/1500 = 0.02A$$

The only thing to take away from this is to remember to convert the kΩ into Ω. Apart from that, if you see this kind of question on the real exam you would chuckle heartily to yourself in glee.

Some more simple questions just to make sure you know the basics of electricity:

Q - How much energy is dissipated by a resistor if a potential difference of 6V is applied to it for 5 minutes and a current of 0.12A flows through it?

$$E = ItV$$
$$E = 0.12*(5*60)*6 = 216\ J$$

Q - If a charge of 5 MC (MegaCoulombs) is moved through a potential difference of 20GV (Giga-Volts), how much energy is transferred?

Mega = 10^6, Giga = 10^9

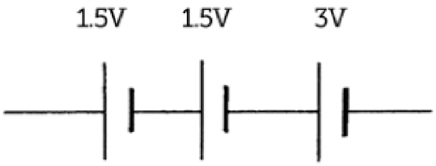
$$V = W/Q,\ W = QV$$
$$W = 5x10^6\ x\ 20\ x\ 10^9 = 10^{17}\ \text{Joules}$$

SERIES AND PARALLEL CIRCUITS

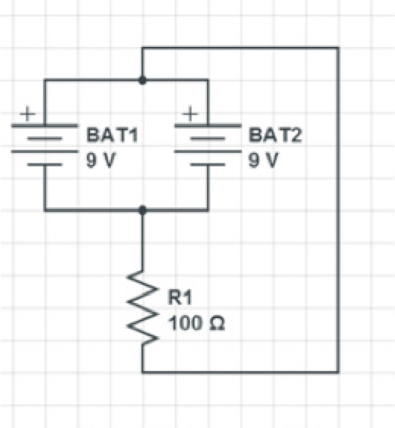
The majority of electricity questions involve some reference to series and parallel circuits. So let's go over some of the basics here:

Cells

When cells are connected in series, the total voltage supplied to the circuit is the sum of the individual voltages of the cells. However, when identical cells are in parallel with each other, the total voltage supplied to the circuit is equal to the voltage of just one of the cells.



Total voltage: 1.5V + 1.5V + 3V = 6V



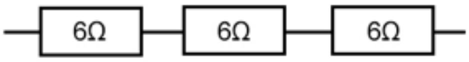
Total Voltage = 9V

Resistors

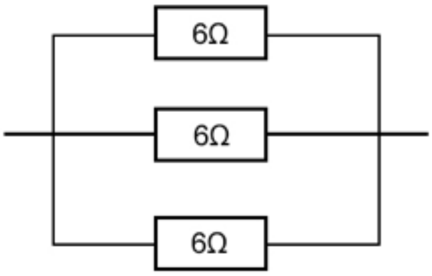
When resistors are in series, their resistances are added together to get the total resistance. When they are in parallel, their total resistance (R_T) is given by

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

This means that the total resistance of the parallel combination is **less than** the resistance of any individual resistor (You can derive this formula from V=IR but that's unnecessary – it's easier just to learn it).



Total Resistance = 6 + 6 + 6 = 18Ω



1/Total Resistance = 1/6 + 1/6 + 1/6 = 1/2

Total Resistance = 2Ω

If there are only 2 resistors present, then you can use the simplified formula to find the total resistance:

$$\text{Resistance} = \frac{\text{Product}}{\text{Sum}}$$

That is, the total resistance of the 2 resistors is the product of their resistance divided by the sum of their resistance. So if you've got resistors of 5Ω and 10Ω respectively, the total resistance is (5x10)/(5+10) = 50/15 = 3.3Ω. As you can see, 3.3Ω is less than both 5Ω and 10Ω.

Current

Most of the questions regarding electricity make reference to series and parallel circuits, and of these questions, the majority involve working out voltages and currents. This is sort of complicated, and conceptually a little weird, so it helps to go over it a couple of times. Let's get started.

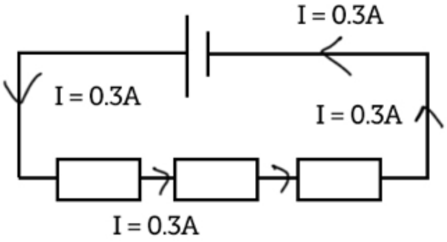
<u>CONSERVATION OF CHARGE</u> – "The total charge flowing into a junction of wires must equal the total charge flowing out of the wires".

This leads to…

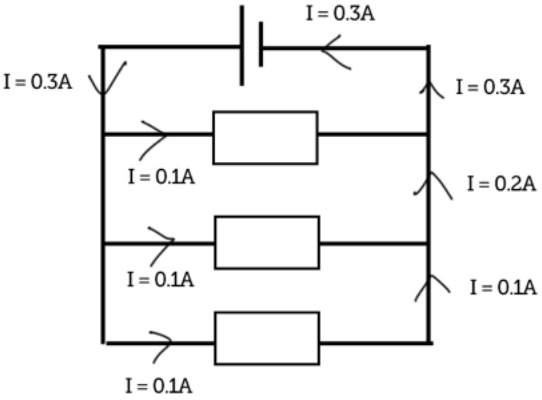
<u>KIRCHOFF'S FIRST LAW</u> – "The sum of the currents flowing into a junction of wires must equal the sum of the currents flowing away from the junction of wires".

We can summarise these somewhat strangely worded laws into one simple statement:

In a parallel circuit, the current splits. In a series circuit, the current is constant throughout.



When drawing circuits, we represent current with a little arrow (as shown here). The arrow points in the direction of **conventional current**, which flows from **positive to negative**. Although electrons themselves flow from negative to positive, the convention was decided years before this was discovered, so when discussing currents, we say that **current flows from positive to negative** (The tall end of the cell is the positive end).



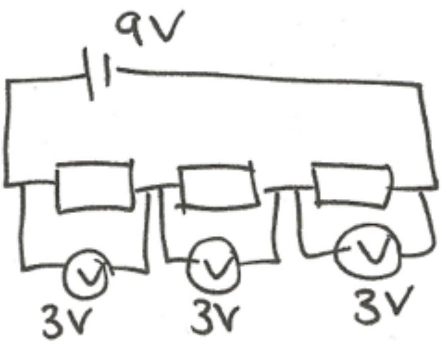
Anyway, as you can see from the series circuit above, the current is the same everywhere in the circuit (since there are no junctions). Current does not get "used up", it is always the same.

In a parallel circuit, the story is slightly different. Thanks to Kirchoff's First Law, we know that the sum of currents flowing into a junction must equal the sum of currents leaving the junction. This is illustrated nicely in the image to the right.

The 0.3A current "splits" into 3 lots of 0.1A, which rejoin to form 0.3A towards the end of the circuit.

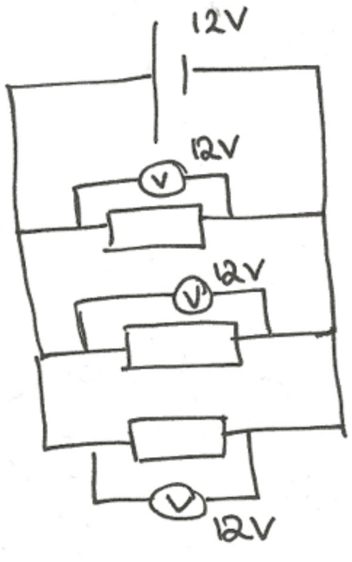
Of course, this even split of currents only applies when the resistances of the parallel sections are equal. If they're not equal, the current is split proportional to the resistance of each section (we'll talk about this after discussing the issue of voltage).

Voltage



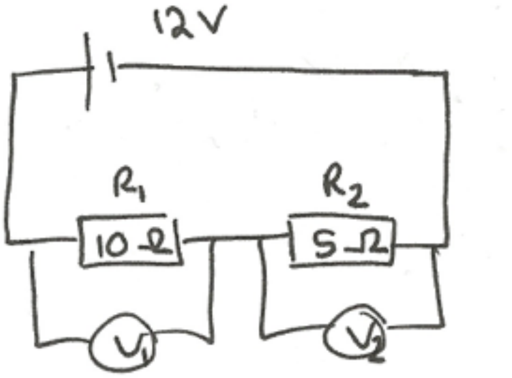
The story with voltage when it comes to series and parallel circuits is almost the opposite of that of current.

In a series circuit, the total voltage supplied by the cell is divided between the components. If the components all have the same resistance, then the voltage across them will be identical. If not, then the ratio of the voltages is equal to the ratio of the resistances (more on this later).



In a parallel circuit however, the voltage supplied by the cell is the same as the voltage across each component in the circuit (as illustrated in the image to the right).

But what if the components in the circuit don't have the same resistance? Let's consider the circuit below.



$$\frac{R_1}{R_2} = \frac{V_1}{V_2}, \quad V_1 + V_2 = 12$$

We need to keep the following 2 laws in mind:

- **The ratio of the voltages is the same as the ratio of the resistances**. In other words:

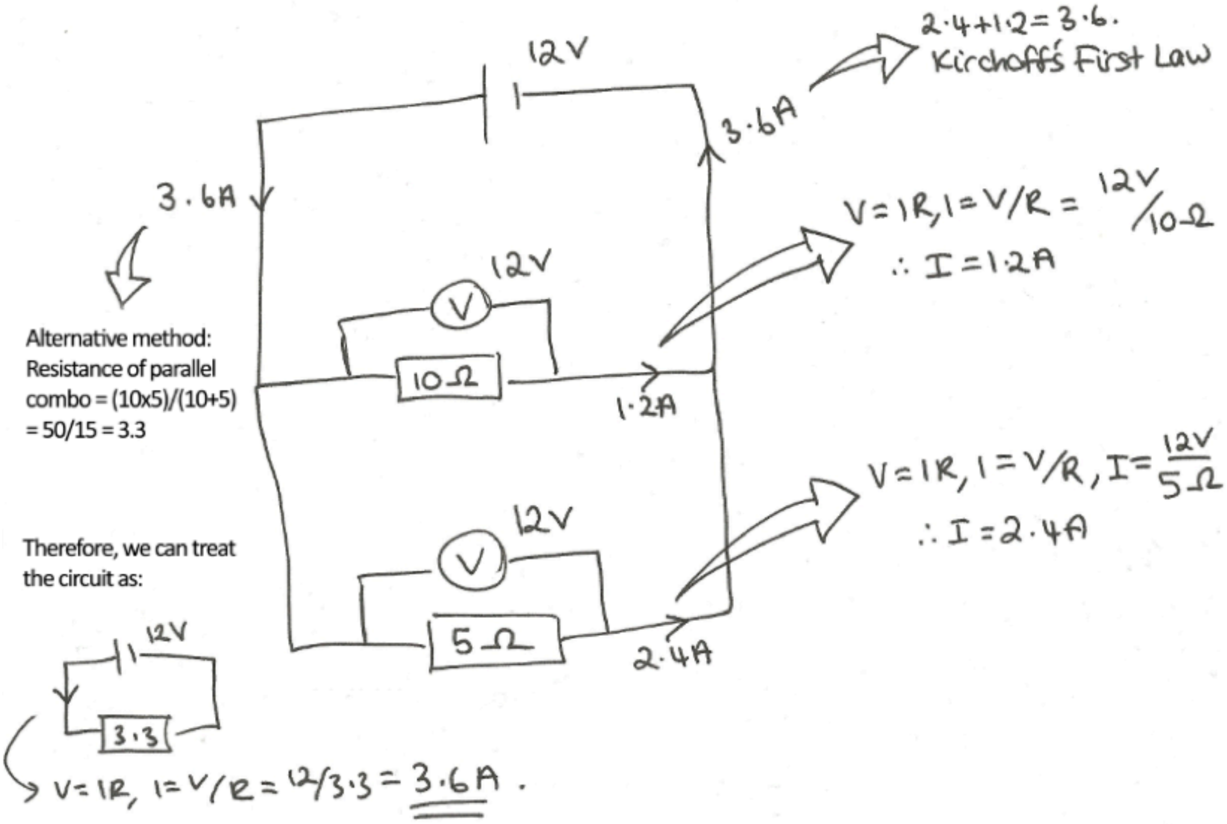
$$\frac{R_1}{R_2} = \frac{V_1}{V_2}$$

- The voltages must add to equal the source voltage. In other words:

V1 + V2 = Source voltage = 12V

So, in this example, with resistors of 10Ω and 5Ω respectively, the maths is quite simple. The 10Ω resistor must have 8V going through it, while the 5Ω resistor has 4V. These numbers are easy (in that 10 is double 5, and splitting 12V into thirds is easy), but even with more difficult numbers, you should be able to do the calculations.

What about current when it comes to circuits with components of varying resistance? We don't need to worry about series circuits, because as we've just seen, the current is constant throughout. Parallel circuits are slightly more problematic. Consider the circuit below:



Alternative method:
Resistance of parallel combo = (10x5)/(10+5) = 50/15 = 3.3

Therefore, we can treat the circuit as:

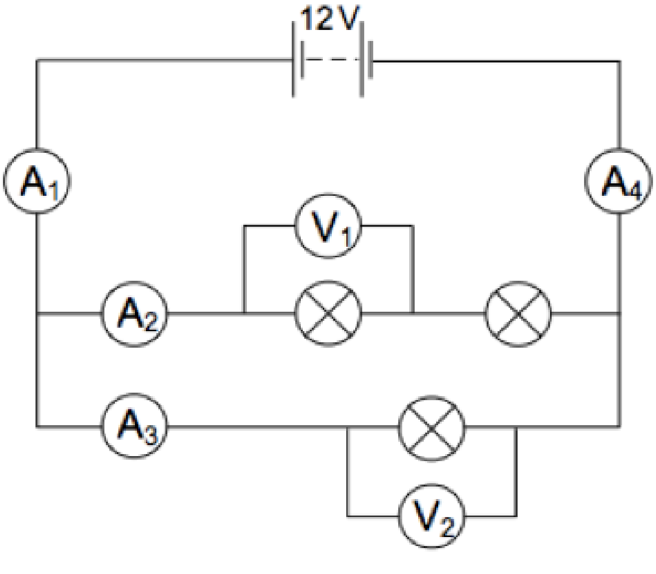
If something like this came up in a question, they would ask us to work out one of the variables (voltage in either resistor, current through either resistor, current through the whole circuit etc). I've shown you in the image how to best calculate these values. The key principle (as always) is Ohm's Law (V = IR), and through that you can calculate pretty much anything.

It's interesting that with voltage, the higher resistance has the higher voltage going through it, but with current, the higher resistance has the lower current through it. This is because voltage is a measure of work (ie: energy), and a greater resistance requires more energy to "push" charge through it. Current, however, is the **rate of flow of charge**, ie (speed of charge, speaking loosely). It makes sense therefore, for a higher resistance to have charge flow through it at a lower rate.

If you wanted to, you could have calculated the current in each resistor with the same method that we used in the voltage calculation – by using the ratios of the resistances. That's completely fine, but you have to remember that unlike voltage, the **higher resistance has the lower current**.

Let's try some proper BMAT past paper questions now.

Q - In this circuit, the bulbs are identical. A_1 to A_4 are ammeters, and V_1 and V_2 are voltmeters.



Which of the statements below are true and which are false for the circuit shown?

1. Voltmeter V_1 reads 6 volts.
2. Voltmeter V_2 reads 12 volts.
3. Ammeter A_2 shows a higher reading than A_3.
4. The reading on A_4 is less than the reading on A_1.
5. The reading on A_4 is the sum of the readings on A_2 and A_3.

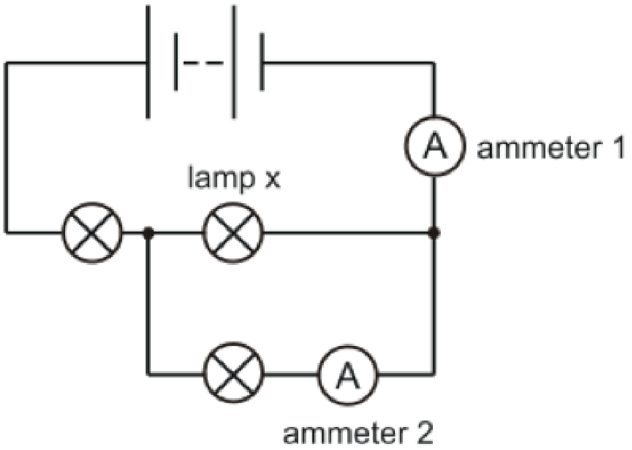
Armed with the knowledge we now have about circuits, we should be able to answer this question.

1. V_1 reads 6 volts – Because this is a parallel circuit, we know that 12V has to be going through both parallel sections. Within the first parallel section however, are 2 bulbs in series. Voltage is shared in

series, so each bulb must have 6V through it. **TRUE**

2. V_2 reads 12 volts – It's a parallel circuit, so 12V needs to be running through both parallel sections. The bottom one only has 1 bulb (ammeters have 0 resistance so they don't count), so all 12V must be going through that one bulb. **TRUE**
3. A_2 shows a higher reading than A_3 – The top parallel section with A_2 has double the resistance of the bottom one with A_3 (because it has 2 bulbs rather than 1). A higher resistance means a lower current. **FALSE**
4. The reading on A_4 is less than the reading on A_1 – Current only splits when it enters a junction, and reforms when leaving a junction. A_1 shows the current before the junctions, A_4 shows the current after the junctions, so the currents must be equal. **FALSE**
5. The reading on A_4 is the sum of the readings on A_2 and A_3 – Kirchoff's first law tells us that current entering a junction must equal the current leaving a junction, so yes, the currents at A_2 and A_3 must add up to give A_4. **TRUE**

Q - This circuit shows three lamps and two ammeters in a circuit.



Lamp X 'blows' (the filament breaks). What happens to the reading on each ammeter, and to the total resistance of the circuit?

	Reading on ammeter 1	Reading on ammeter 2	Total resistance of circuit
A	decreases	decreases	decreases
B	decreases	decreases	increases
C	decreases	increases	decreases
D	decreases	increases	increases
E	increases	decreases	decreases
F	increases	decreases	increases
G	increases	increases	decreases
H	increases	increases	increases

This is a nice question because it really tests your understanding of circuits, and has lots of potential traps within it.

TOTAL RESISTANCE – We're losing a lamp from the circuit. The uneducated layman might think that this means the resistance decreases, but we know better. The lamp in question was lost from a parallel combination. We know that the total resistance of a parallel combination is less than the sum of the resistances of its parts. Therefore, with the bulb working, the total resistance of the parallel combination would have been half that of an individual bulb. But with the bulb gone, we no longer have a parallel combination, so the resistance of that section is the same as that of an individual bulb. Therefore, the total resistance **INCREASES**.

READING ON AMMETER 1 – Ammeter 1 is found after all the junctions, which means it's a measure of total current in the circuit. We've just worked out that total resistance increases. This means that total current must decrease (because current is a measure of rate, and a higher resistance means a lower rate of flow of charge).

READING ON AMMETER 2 – When the bulb was intact, the reading on Ammeter 2 would have been half of that of ammeter 1 (current splits evenly between the two parallel sections). But when the bulb blows, we effectively have a series circuit with 2 bulbs and 2 ammeters. Both ammeters have to read the same value, and so Ammeter 2's reading will increase compared with when the bulb was intact.

The answer is therefore D.

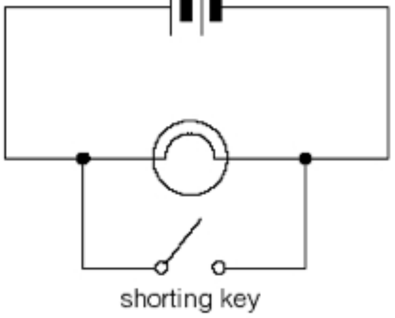
Bonus question: what will be the relative brightness of the 3 bulbs in the intact circuit?

Let's imagine the cells provide 12V in total, and the bulbs all have a resistance of 10Ω (random numbers that are easy to work with). The total resistance of the parallel combination will therefore be 5Ω.

We know that the ratio of the voltages is the same as the ratio of the resistances, which means that the first bulb (10Ω) must have twice the voltage as the parallel combination (5Ω). So we know that the first bulb must have 8V going through it, while the parallel combo has 4V. However, voltage in a parallel circuit does not split, which means each bulb in the parallel combination will have 4V running through it. Voltage is a measure of work (ie: energy), so the bulb with 8V will be twice as bright as the other bulbs with 4V each.

SHORT CIRCUIT

You've probably heard the term "short circuit" before, and should know what it means if you paid attention in GCSE Physics. Let's just go over it briefly.

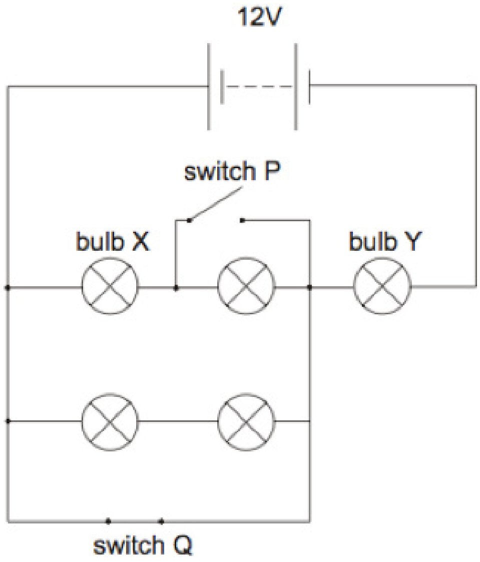


Charge prefers the path of least resistance, much like everything else in life. We came across this concept earlier as well when we found out that a 10Ω resistor has half the current through it as a 5Ω resistor. Of course, this only applies to parallel circuits, as in a series circuit, charge has no choice but to go through every component.

Consider the circuit on the left. When the switch is closed, the charge will prefer to flow through the wire rather than the bulb, as wire basically has no resistance (well, it has a tiny tiny bit).

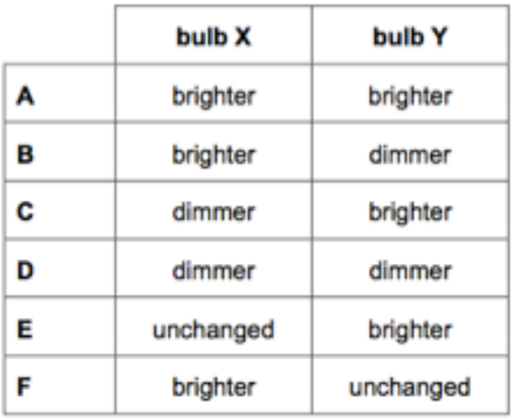
Because this tiny tiny bit is far far smaller than the resistance of the bulb, all of the charge effectively flows through the wire and none flows through the bulb. That is what we mean by a "short circuit" – the charge bypasses the component by taking the path of least resistance. We'll need this knowledge for the next few questions.

Q - The circuit shows give identical filament bulbs designed to work at 12V connected in a circuit with two switches. Switch P is initially open and switch Q is initially closed.



Switch P is then closed and switch Q is opened.

Compared with their brightness before these changes were made, how has the brightness of bulbs X and Y changed?



	bulb X	bulb Y
A	brighter	brighter
B	brighter	dimmer
C	dimmer	brighter
D	dimmer	dimmer
E	unchanged	brighter
F	brighter	unchanged

So let's take a look at what happens before the switches change, and after they do.

BEFORE: All of the charge will bypass the 4 parallel bulbs (through switch Q) and only flow through bulb Y. Bulb Y will therefore have all 12V running through it, and will be at maximum brightness.

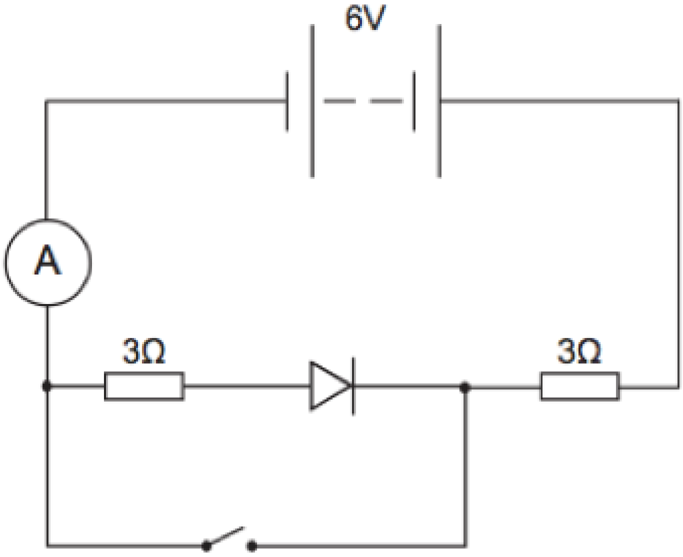
AFTER: Switch Q is now closed, so we no longer have 4 bulbs being short circuited. Bulb X has some charge flowing through it now, so regardless of how much actually is, the bulb will be brighter than it was before. Bulb Y now has less than 12V flowing through it, as some (doesn't matter how much) voltage is being taken up by the parallel combination, so it must be dimmer than it was before.

The answer therefore, has to be **B**. Notice we didn't have to do any calculations or anything, we just had to recognize that X must be somewhat brighter than before, and Y must be dimmer.

DIODES

This is a diode. A diode normally does nothing. It's basically a piece of wire, provided it is placed in "forward bias" – meaning, the "arrow" is pointing in the direction of (conventional) current. However, if the arrow is pointing opposite to the direction of conventional current, then the diode is said to be in "reverse bias" and acts as a break in the circuit, ie: **no charge can pass through it**.

Q - Consider this circuit. What is the reading in the ammeter when the switch is open and when the switch is closed?



This is a very sneaky question. A casual glance will reveal the presence of a diode. As we've just found out, we only have to worry about diodes when they are in reverse bias, and this one appears to be in forward bias, so everything's good, right? Unfortunately, that isn't quite the case. If you look closely at the battery, you'll find that the long line (positive) is to the right of the short line (negative) when in almost every other instance they're the other way around. This means that in this circuit, conventional current (which flows from positive to negative), flows clockwise around the circuit (even though we are normally used to it flowing counterclockwise). Therefore, the diode is in fact, in reverse bias, and so it acts as a break in the circuit.

Now that we know that, the rest is easy. When the switch is open, we have 2 breaks in the circuit, so no charge can flow anywhere. The reading on the ammeter will therefore be 0.

When the switch is closed, charge can bypass the diode and the second bulb via the switch (short circuit), but will still go through the first 3Ω resistor. The total resistance in the circuit is therefore 3Ω. V = IR, I = V/R = 6/3 = 2.0A.

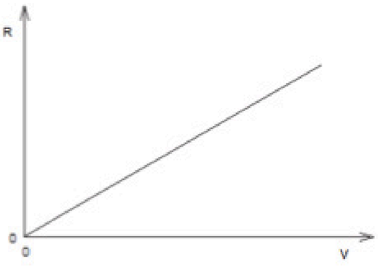
OHMIC CONDUCTORS

Whether or not you strictly "need to know" this is debatable. There's only been one question on it, shown below, and it's possible to answer it without actually knowing anything about the topic of ohmic conductors. However, we feel it's better to be safe than sorry, and if something does come up, that one mark could potentially be the difference between a mediocre score in the 5s and a good score in the 6s. A great resource for learning about this topic is www.physicsnet.co.uk (http://physicsnet.co.uk/a-level-physics-as-a2/current-electricity/current-voltage-characteristics/). In fact, that website is fantastic way of learning physics period, so if at the end of the course and after reading through this booklet, if you're still unclear about stuff, you should give it a visit.

Q - Which graph correctly shows how the resistance (R) varies with applied voltage (V) for a resistor at constant temperature?

A

B



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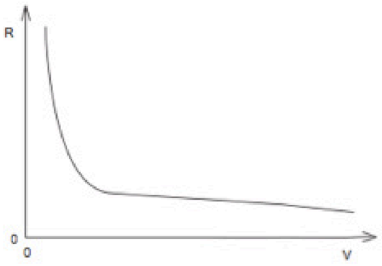

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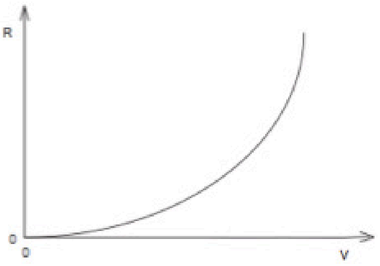

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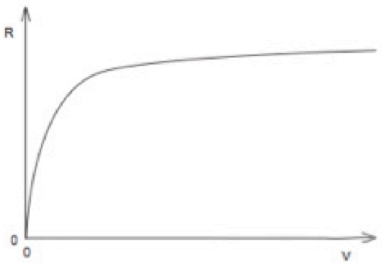

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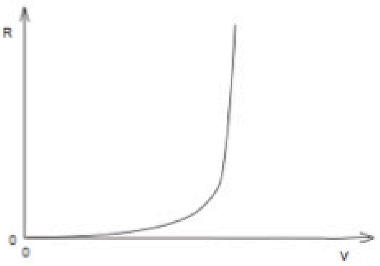
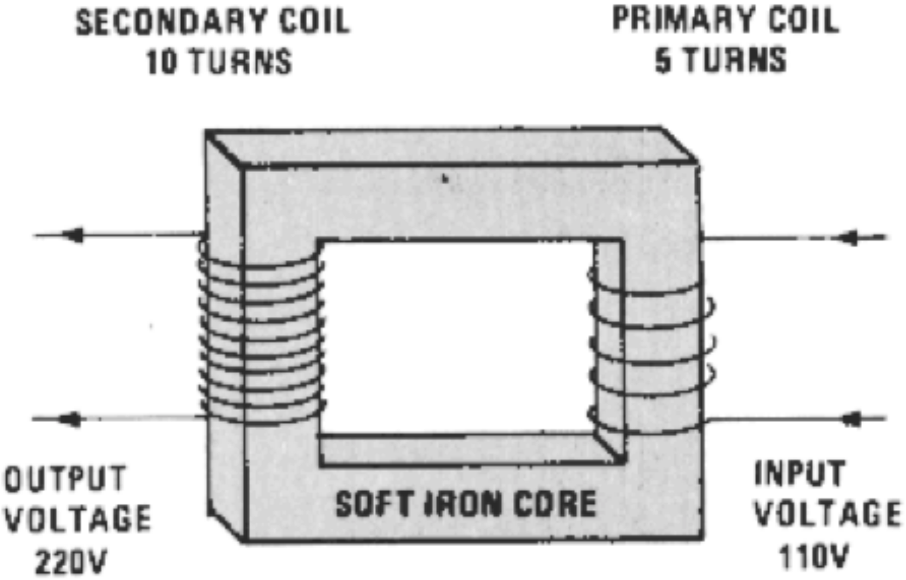


You don't really need to know anything about ohmic conductors or characteristic graphs to answer this question. A resistor always has the same resistance, unless temperature is changed. But because the question specifies "at constant temperature", the resistance must be constant throughout. The answer therefore, has to be **A**.

TRANSFORMERS

A transformer is a device that changes voltage and current, whilst keeping power the same. When electricity is transported around the national grid, "step-up" transformers are used to make very high voltages (400kV) and therefore very low currents (P = IV, if V increases then I decreases). Low currents are helpful because a higher current means more energy will be lost as heat. The cost of building these transformers is far less than the cost of the electricity that would otherwise have been wasted as heat.



There's really only one thing you need to know to answer the majority of transformer questions:

$$\frac{n_1}{n_2} = \frac{v_1}{v_2}$$

Where n_1 is the number of turns on the primary coil and n_2 is the number of turns on the secondary coil. Naturally, v_1 and v_2 are each coil's respective voltage.

If the secondary coil has more turns than the primary, the voltage is stepped up (ie: increased). If the primary coil has more turns then the voltage is decreased (this is helpful when electricity has reached houses to step it down to a more manageable voltage).

They've never asked a question that required you to know how transformers actually work, but it's an interesting topic that you may feel like looking up in your spare time :)

Anyway, let's get these questions done.

Q - A 100% efficient transformer has 1500 turns on its primary coil. The input to the transformer is

250V ac. The output current is 10A and the output power is 0.5kW.

What is the number of turns on the secondary coil?
$n_1 = 1500$, $v_1 = 250$. We want to work out n_2 and so we need to know v_2. P = IV, V = P/I = 500W/10A = 50V. (Remember, 0.5kW needs to be converted to the standard unit of W).

$$\frac{1500}{n_2} = \frac{250}{50}$$

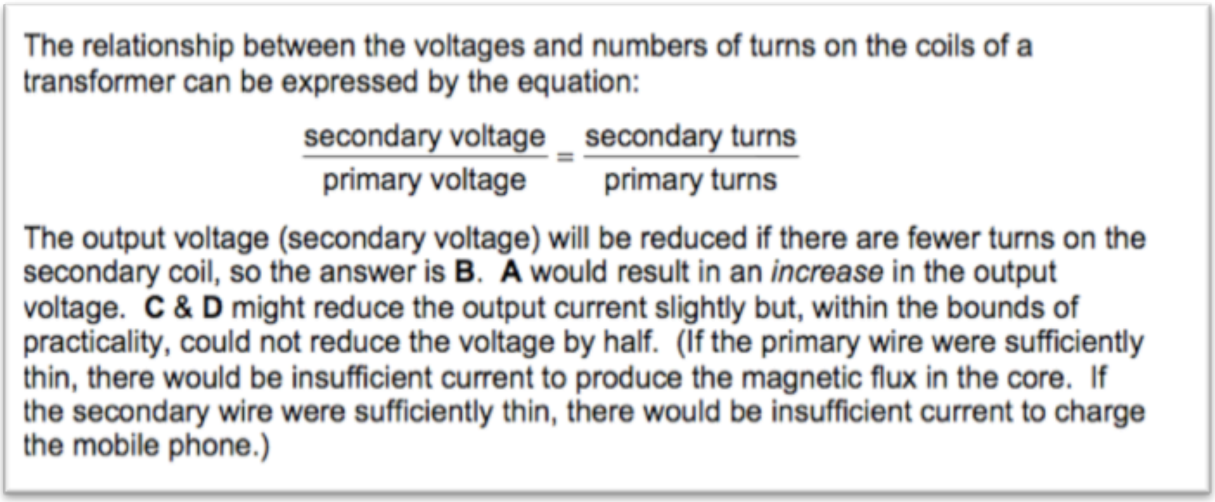
$$\frac{1500}{n_2} = 5, n_2 = \frac{1500}{5} = \mathbf{300}\ \text{turns}$$

Q - A charger unit for a mobile phone contains a transformer. In use the primary coil of the transformer is connected to the mains supply and the secondary coil provides a low voltage output. If the transformer were to be re-designed to produce half the voltage output, which one of the following could achieve this?

1. Fewer turns on the primary coil
2. Fewer turns on the secondary coil
3. Thinner wire for the primary coil
4. Thinner wire for the secondary coil

Nice, easy question. The formula tells us that the ratio of the turns is the same as the ratio of the voltages. So if the secondary coil has less turns, the output voltage is less. The answer is therefore B.

This particular question was from the specimen paper, which means it has a worked solution online. To save you the trouble of finding it yourself (http://www.admissionstestingservice.org/images/20447-specimen-section-2-answers.pdf) I've attached a screenshot here.



The relationship between the voltages and numbers of turns on the coils of a transformer can be expressed by the equation:

$$\frac{\text{secondary voltage}}{\text{primary voltage}} = \frac{\text{secondary turns}}{\text{primary turns}}$$

The output voltage (secondary voltage) will be reduced if there are fewer turns on the secondary coil, so the answer is **B**. **A** would result in an *increase* in the output voltage. **C & D** might reduce the output current slightly but, within the bounds of practicality, could not reduce the voltage by half. (If the primary wire were sufficiently thin, there would be insufficient current to produce the magnetic flux in the core. If the secondary wire were sufficiently thin, there would be insufficient current to charge the mobile phone.)
