For full marks, show all your working in calculations. Give all answers to three (3) significant figures.

Additional Data & Formulae:

$F = kq_1q_2/d^2$
$k = 9.00 \times 10^9$ N m^2 C^{-2}

Question 1: **[3 marks]**

Rapunzel has been combing her long golden hair with a plastic comb. After she has finished, she places the comb on her plastic desk next to some small pieces of a torn up letter from Prince Charming. She notices the pieces of paper are attracted to the comb and stick to it. Explain her observation in terms of the physics principles involved.

- Valence electrons can be transferred from one object to another as a result of rubbing them together (as has occurred during the combing). NB: it is not necessary to predict whether electrons are transferred from the hair to the comb or vice-versa, just to understand that electron transfer has occurred.
- Each object will become charged since electrons carry a negative charge
- The object which gains electrons will become negatively charged and the object which loses electrons will become positively charged.
- When the charged comb is placed near the pieces of paper, it will induce an opposite charge in the pieces of paper.
- As a result of this opposite charge, the pieces of paper will be attracted to the comb.
- The significance of the plastic desk is that plastic is a non-conductor, otherwise the comb's charge would be conducted away.

(1/2 mark for each of the above points).

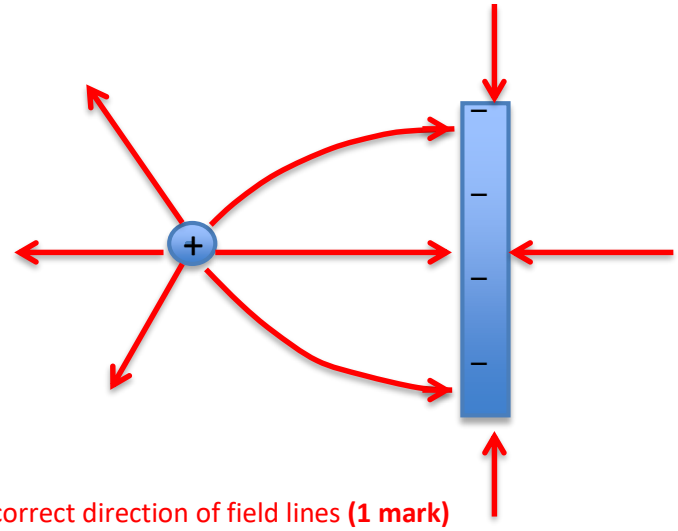
Question 2: **[3 marks]**

Merlin tosses two metallic balls directly up into the air and they 'magically' acquire opposite charges. Calculate the magnitude and direction of the force which exists between two balls which are 15.0 cm apart. One has a charge of +300 μC and the other has a charge of -230 μC.

$F = (kq_1q_2)/d^2$ **(1 mark)**
$= (9.00 \times 10^9 \times 300 \times 10^{-6} \times -230 \times 10^{-6})/(0.150)^2$ **(1 mark)**
$= -2.76 \times 10^4$ N
$= 2.76 \times 10^4$ N force of attraction **(1 mark)**

Question 3: **[3 marks]**

Draw the electric field lines around the two charged objects in the diagram below. Include the field lines which occur in the space between them. NB: No more than 10 field lines are required.



- correct direction of field lines **(1 mark)**
- straight lines towards/away from charged objects where no interaction occurs **(1 mark)**
- correct representation of field lines in the space between the objects **(1 mark)**
- NB: ideally, the number of field lines around each object should be even and they should be symmetrical. There can be a tendency to have a greater number of field lines in the space between the two objects in order to better show the distribution. However, this implies, incorrectly, that there is a greater density of field that space.

Question 4: **[3 marks]**

Dr. Frankenstein passes an electric current through his 'creature' in order to bring it to life. If he uses a charge of 3.125×10^{23} eV for 8.00 seconds, what is the magnitude of the current which is passed through the creature.

$q = (3.125 \times 10^{23}\ eV)/(1.60 \times 10^{-19}\ eV\ C^{-1})$
$= 5.00 \times 10^{4}\ C$ **(1 mark)**

$I = q/t$ **(1 mark)**
$= 50{,}000/8.00$
$= 6.25 \times 10^{3}\ A$ **(1 mark)**

Question 5: **[2 marks]**

Explain the difference between conventional current and electron flow?

Conventional current refers to the direction of flow of positive charge in a circuit. **(1 mark)**

Electron flow refers to the direction of flow of negative charge (electrons) in a circuit. **(1 mark)**

Question 6: **[8 marks]**

Calculate the following:

a) Little Red Riding Hood is making tea for 'granny'. What is the power of the kettle if it draws a current of 15.0 A from the mains electricity? (2 marks)

$P = IV$ **(1 mark)**
$= 15.0\ A \times 240\ V$
$= 3.60 \times 10^3\ W$ **(1 mark)**

b) The King of Hearts is mixing the batter for his tarts with a 100 W mixer (it is the Queen's day off). What current will be drawn if it is connected to a 240 V supply? (2 marks)

$I = P/V$ **(1 mark)**
$= 100\ W/240\ V$
$= 0.417\ A$ **(1 mark)**

c) Sleeping Beauty's clock radio has failed to wake her up for 100 years. What is the power of the clock radio if it has a resistance of 1.50 kΩ and draws a current of 0.147 A? (2 marks)

$P = I^2R$ **(1 mark)**
$= 0.147^2 \times 1.50 \times 10^3$
$= 32.4\ W$ **(1 mark)**

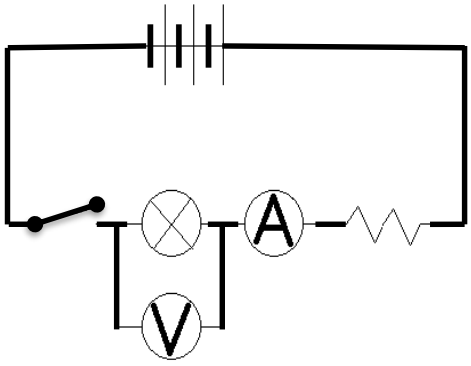
d) Aladdin has swapped his old golden lamp for a shiny new "Genie" brand electric lamp. What is the power of the globe in the electric lamp if it has a resistance of 0.300 Ω and is connected to a 12.0 V dry cell? (2 marks)

$P = V^2/R$ **(1 mark)**
$= 12.0^2/0.300\ \Omega$
$= 480\ W$ **(1 mark)**

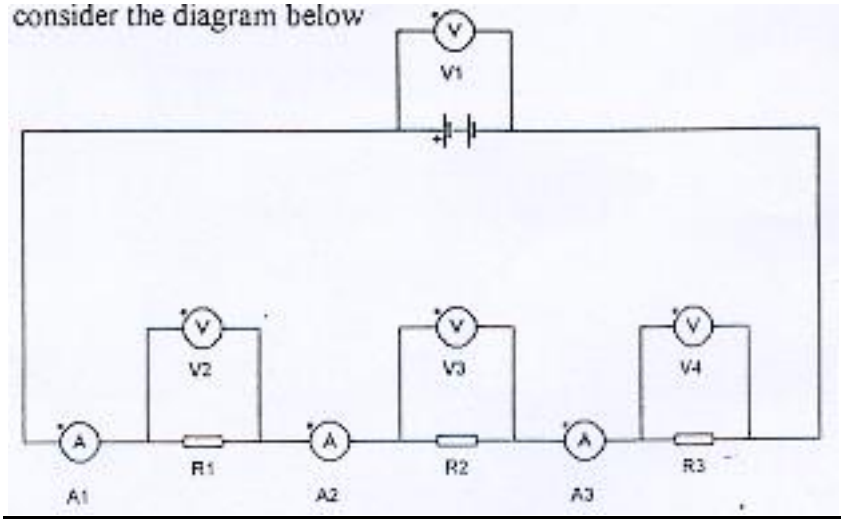
Question 7: **[3 marks]**

A student is conducting an electrical investigation and constructs a circuit which contains a switch, a fixed resistor and a lamp all connected in series with a power pack. The student also has a voltmeter connected to measure the potential across the lamp, and an ammeter which is being used to measure the current supplied to the resistor. Draw a diagram for this circuit.

½ mark for each component – all must be in series except for the voltmeter which must be in parallel with the lamp.



Questions 8-10 refer to the diagram below:



Question 8: **[1 mark]**

Write an equation that expresses the relationship between V_1, V_2, V_3 and V_4.

Series circuit, ∴ EMF is divided amongst the circuit elements
$\therefore V_1 = V_2 + V_3 + V_4$

Question 9: **[1 mark]**

Write an equation that expresses the relationship between A_1, A_2 and A_3.

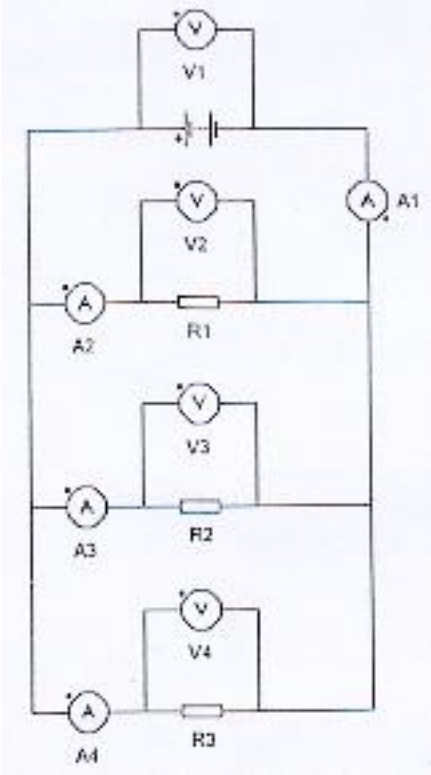
Series circuit, ∴ current is the same through each circuit element
$\therefore A_1 = A_2 = A_3$

Question 10: **[1 mark]**

If R_1, R_2 and R_3 each have a resistance of 30.0 Ω, what is the effective resistance in the circuit?

Series circuit $\therefore R_E = R_1 + R_2 + R_3$
$= 30.0 + 30.0 + 30.0$
$= 90.0\ \Omega$

Questions 11-13 refer to the diagram below:



Question 11: **[1 mark]**

Write an equation that expresses the relationship between V_1, V_2, V_3 and V_4.

Parallel circuit, ∴ EMF is the same across each circuit element
$\therefore V_1 = V_2 = V_3 = V_4$

Question 12: **[1 mark]**

Write an equation that expresses the relationship between A_1, A_2 and A_3.

Parallel circuit, ∴ current is divided amongst the circuit elements
$\therefore A_1 = A_2 + A_3 + A_4$

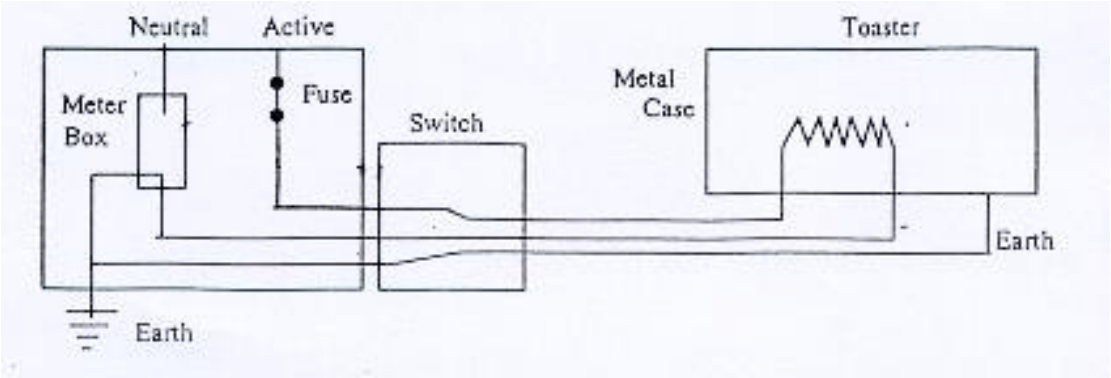
Question 13: **[1 mark]**

If R_1, R_2 and R_3 each have a resistance of 30.0 Ω, what is the effective resistance in the circuit?

Parallel circuit $\therefore$ $1/R_E = 1/R_1 + 1/R_2 + 1/R_3$
$= 1/30.0 + 1/30.0 + 1/30.0$
$= 10.0\ \Omega$

Question 14: **[8 marks]**

Wayne Manor has a 240 V, 1600 W electric toaster which has a power cord which is far too long and Robin keeps tripping over it and pulling the plug from the wall. Batman wants his toast so Alfred is trying to solve the problem. Alfred is definitely not an electrician! The diagram below shows the electric toaster connected to the domestic electrical circuit.



Alfred wished to shorten the cord on the toaster and began work while the plug was in and switched on. After taking off the outer metal case he undid the neutral wire from its terminal. Surprised at his good fortune (for not getting a shock!!), and realising the error of his ways, Alfred unplugged the toaster before continuing.

Give physics-based answers to the following questions:

(a) Explain why Alfred did not get a shock even though the toaster was plugged in and switched on. (2 marks)

- Even though the toaster is switched on at the wall, it was not actually in operation at the time
- Alfred only touched the neutral wire, so he did not act as a 'switch', completing a circuit.
- Although he removed the casing, this is attached to the earth wire and is designed so that a shock cannot be received from it.
- if he had touched the active wire instead, he would have received a shock since there would have been active voltage present in the socket.

(1 mark each up to a maximum of 2 marks for making any of the above points)

(b) Alfred cut the cord and reconnected the three-pin plug. In the process, however, he connected the earth wire to the active (phase) pin, and the active wire to the earth. Explain whether the toaster will still operate or not. (2 marks)

The toaster will not operate **(1 mark)** since the active wire is now connected to the earth pin, and there will be no current supplied to the toaster element. **(1 mark)**

Question 14 (Contd)

(c) Explain the function and purpose of an RCD and whether or not it will be tripped. (2 marks)

A Residual Current Device is designed to detect any difference in the magnitude of the current flowing in the active and neutral conductors. If any such difference is detected (usually indicating loss of current through a faulty device or through a person) the supply will be cut off in milliseconds (i.e. the switch will be 'tripped'). **(1 mark)**
In the example given above, there was no loss of current (since Alfred did not get a shock and the fuse wasn't blown) and, therefore, an RCD would not have been tripped. **(1 mark)**

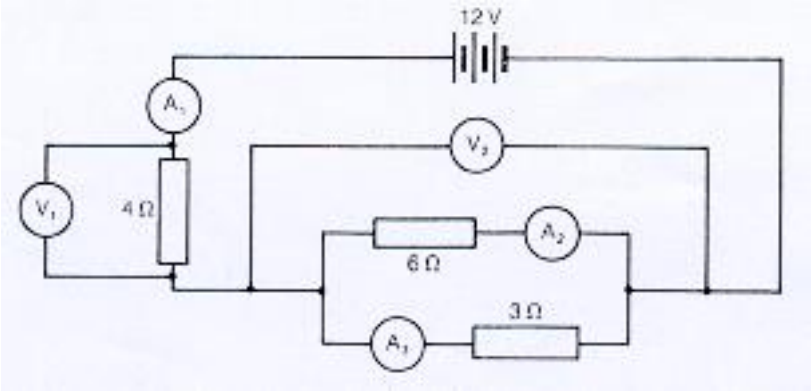
(d) Is the toaster now a safety hazard? Explain. (2 marks)

Yes, the toaster is a safety hazard since the active wire is attached to the casing. If someone were to plug the toaster in and attempt to operate it, they would get an electric shock. **(1 mark)**

Since there is no RCD present, this would be likely to be a fatal shock since the fuse would not burn out quickly enough to prevent a shock. **(1 mark)**

Question 15: **[5 marks]**

In the circuit diagram below, calculate the current readings on the ammeters A_1, A_2 and A_3 and the potential difference readings on the voltmeters V_1 and V_2.



(a) Current showing on A_1: (1 mark)

$R_E(total) = 4.0\ \Omega + (1/6 + 1/3)^{-1} = 6.0\ \Omega$
$\therefore I(total) = V(total)/R_e(total) = 12/6.0 = 2.0$ A
Since A1 is in series, it will read 2.0 A

(b) Current showing on A_2: (1 mark)

$R = 6.0\ \Omega$; V = 4.0 V (from (e))
$I = V/R = 4.0/6.0 = 0.667$ A

(c) Current showing on A_3: (1 mark)

$R = 3.0\ \Omega$; V = 4.0 V (from (e))
$I = V/R = 4.0/3.0 = 1.33$ A

Question 15 (Contd)

(d) Potential difference showing on V_1: (1 mark)

From (a), I = 2.0 A, R = 4.0 Ω
∴ V = IR = 2.0 A x 4.0 Ω = 8.0 V

(e) Potential difference showing on V_2: (1 mark)

V(Total) = V_1 + V_2 (since the elements are in series)
∴ V_2 = 12.0 – 8.0
= 4.0 V

Question 16 **(9 marks)**

A student was investigating how current varied with voltage for two resistors combined in series in a circuit. The data obtained is presented in the table below:

Table 1: Current measured at various voltages for two resistors ("P" and "Q") combined in series.

	Voltage (V)				
	2.0	**4.0**	**6.0**	**8.0**	**10.0**
Current (A) Resistor "P"	1.0	1.8	2.5	2.8	3.0
Current (A) Resistor "Q"	1.5	3.0	4.5	6.0	7.5

(a) plot the I-V characteristic of these two resistors on the graph below, as well as the I-V characteristic of the series combination. You may use the blank row in the table to calculate the values for the series combination. (5 marks)

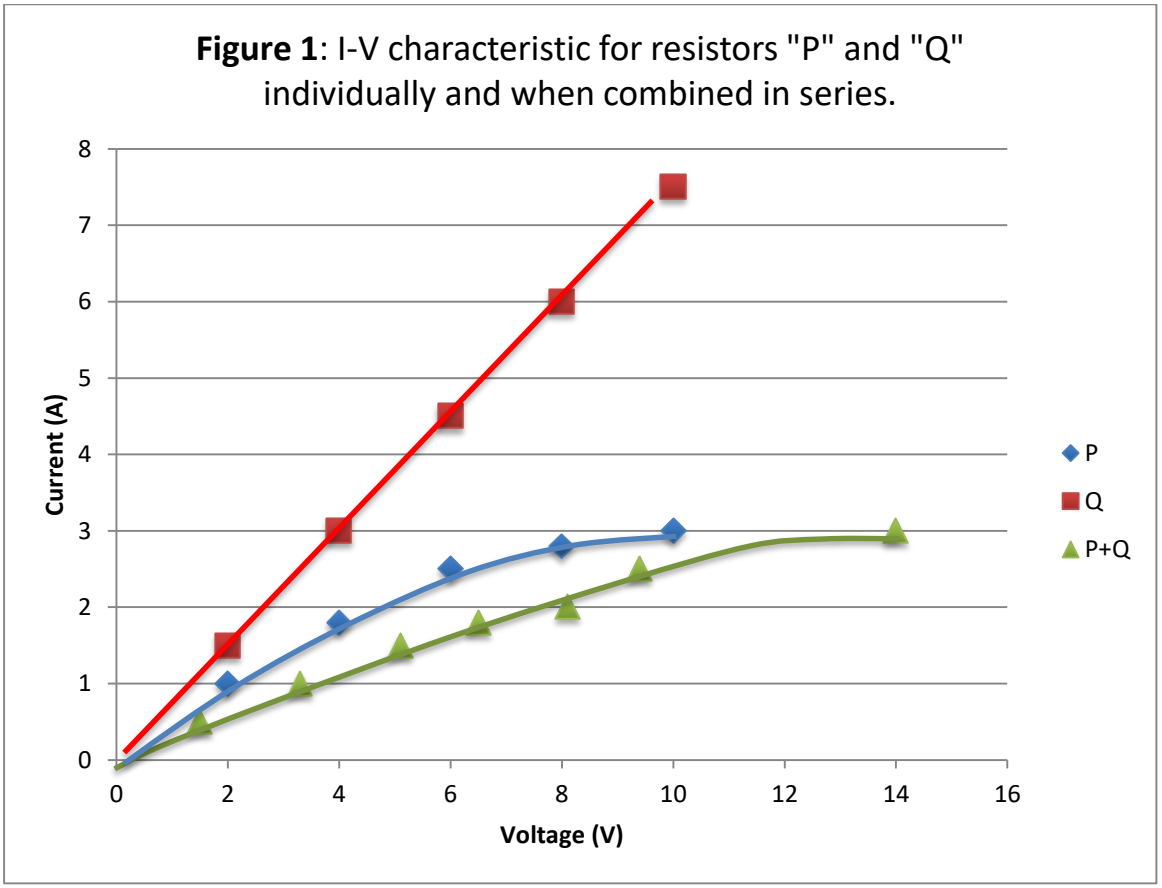
(b) Are the resistors ohmic or non-ohmic? Give a brief reason for your answer and refer to your graph. (2 marks)

Resistor "P" is non-ohmic since the I-V characteristic is not a straight line on the graph i.e. it does not obey Ohm's Law **(1 mark)**
Resistor "Q" is ohmic since its I-V characteristic is a straight line i.e. it does obey Ohm's Law.
(1 mark)

(c) From your graph, determine the effective resistance for the combination at 5.0 V. (2 marks)

At 5.0 V the current is ~1.5 A **(1 mark)**
R_e = V/I
= 5.0/1.5
= 3.33 Ω **(1 mark)**

Question 16 (Contd)



- Graph title **(1 mark)**
- Axes titles with units **(1 mark)**
- Uniform scale on axes **(1 mark)**
- Data plotted correctly **(1 mark)**
- Combined I-V characteristic correct (added across) **(1 mark)**

End of Test