BRITISH PHYSICS OLYMPIAD

British Physics Olympiad 2012

BPhO Round 2

Wednesday 1st February 2012

Time allowed 3hrs plus 15 minutes reading time. There are five questions.
Graph paper and a scaled rule are needed for this examination. Attempt all questions.
A standard formula sheet may be used.

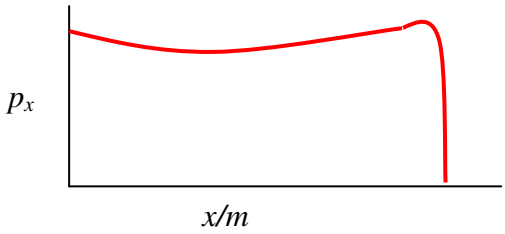
Mass of the Sun	M_{sun}	1.98×10^{30}	kg
Earth-Moon distance	R_{ME}	3.84×10^{8}	m
Earth-Sun distance	R_{ES}	1.50×10^{11}	m
Venus Sun distance	V_{VS}	1.05×10^{11}	m
Mean radius of the Earth	R_E	6.40×10^{6}	m
Permeability of free space	μ_o	$4\pi \times 10^{-7}$	H m^{-1}
Density of Gold	d_{au}	1.93×10^{4}	kg m^{-3}
Molar mass of Gold	M_{au}	19.6	g mol^{-1}
Resistivity of Gold	ρ_{au}	2.44×10^{-8}	Ω m
Avogadro number	N_A	6.02×10^{23}	mol^{-1}
Hubble Constant	H	74 ± 3	km s^{-1} Mpc^{-1}
Parsec	pc	3×10^{16}	m
Charge on an electron	e	-1.6×10^{-19}	C
Mass of an electron	m_e	$9.1 \times 10^{--31}$	kg
Mass of a proton	m_p	1.67×10^{-27}	kg
Mass of a neutron	m_n	1.67×10^{-27}	kg
Universal Gravitational Constant	G	6.67×10^{-11}	m^3 kg^{-1} s^{-2}

Q1

In this question you are asked to make reasoned estimates, assumptions and explanations. These must be clearly stated.

(a)

Figure 1.1



(i) The planet Venus orbits the Sun and is nearer the Sun than the Earth is. Viewed through weak binoculars Venus can often seem to be crescent shaped. Its size and shape appear to change some time later. Why is this?

(ii) The planet Venus does not appear to change in this way viewed by the naked eye. However, its brightness does vary throughout its orbit. How and why?

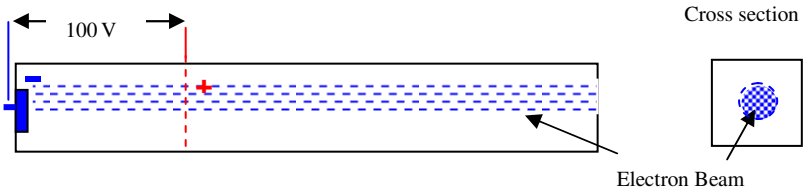
(iii) It was realised in the 18th century that if two telescopes on different parts of the Earth measured the position of Venus at the same time, the distance of the Earth to Venus could be determined and hence the scale of the Solar System. The radius of the Earth was quite well known. With the backing of the Royal Society, Captain Cooke performed the experiment when an eclipse of the Sun by Venus occurred (appearing as a black dot crossing the surface of the Sun). Why did he need the eclipse of the Sun? Why did he go to the South Pacific? Explain.

(iv) A long hose is connected to a tap. If the end of the hose is partially covered by a thumb, the water seems to squirt out much faster. Explain.

(v) Alpha radiation is observed and photographed digitally in a cloud chamber. The density of the track, ('light' pixels/per unit length p_x), is plotted against distance from the source (x). Explain the shape of the graph in *Figure 1.1*.

(b)

Figure 1.2



A beam of electrons is accelerated through a p.d. of 100 V in a high vacuum tube, *Figure 1.2*. There is no external magnetic field. The beam current is 1 μA. The diameter of the cross section of the circular beam is 0.5 mm. Assume the electrons are constant density per unit area across the beam. Calculate:

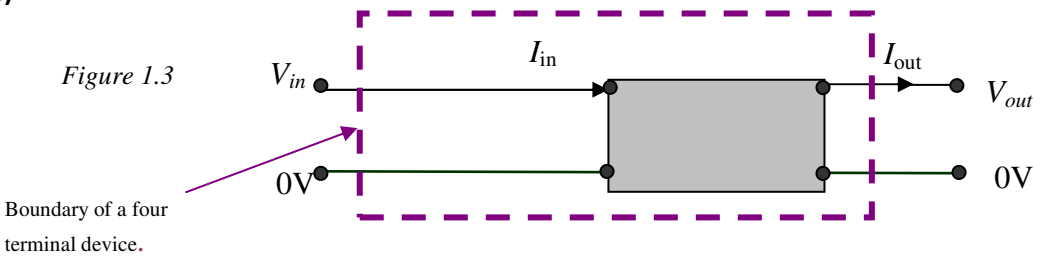
(i) The maximum velocity of the electrons.

(ii) The velocity of electrons after they have travelled half the distance in the accelerating field.

(iii) The magnetic field a distance of 5 mm from the *centre* of the beam.

(iv) What happens if the accelerating p.d. is increased to 100 kV?

(c)



(i) *Figure1.3* shows an active four terminal device (it has internal power supplies). I_{in} is very small and the output behaves as if it is of p.d. V_{out} and internal resistance *r*, where *r* is a constant. Draw a very simple circuit that will behave in this way.

(ii) Show that if the resistance *r* is *large* compared to the resistance of the subsequent resistors in a complete circuit then the current I_{out} will be constant and the device will act as a constant current source. What is the condition for a constant voltage source? Suggest a circuit for a constant voltage source.

Q2

(a) In cosmology it is thought that the Universe is expanding and this results in an apparent velocity of recession V_H. This velocity is related to the distance from the observer R_0 by the equation:

$$V_H = HR_0$$

H is Hubble's constant. A very distant galaxy at present (time t_0) is observed to be R_0 away. How would you expect the distance of the galaxy to change with time?

(b) It can be shown that in the case of a number of atoms with one electronic energy level E, of value ε above the ground state, the number of electrons, n_1 in E is related to the number in the ground state n_0 by the equation:

$$\frac{n_1}{n_0} \approx e^{-\frac{\varepsilon}{kT}}$$

Where *T* is the absolute temperature and *k* is the Boltzman constant. Show that if the atom has two electronic levels E1 and E2 of energy ε_1 and ε_2 above the ground state then if $n_1 << n_0$ and $n_2 << n_0$ then:

$$\frac{n_2}{n_1} \approx e^{-\frac{\varepsilon_2 - \varepsilon_1}{kT}}.$$

Q3

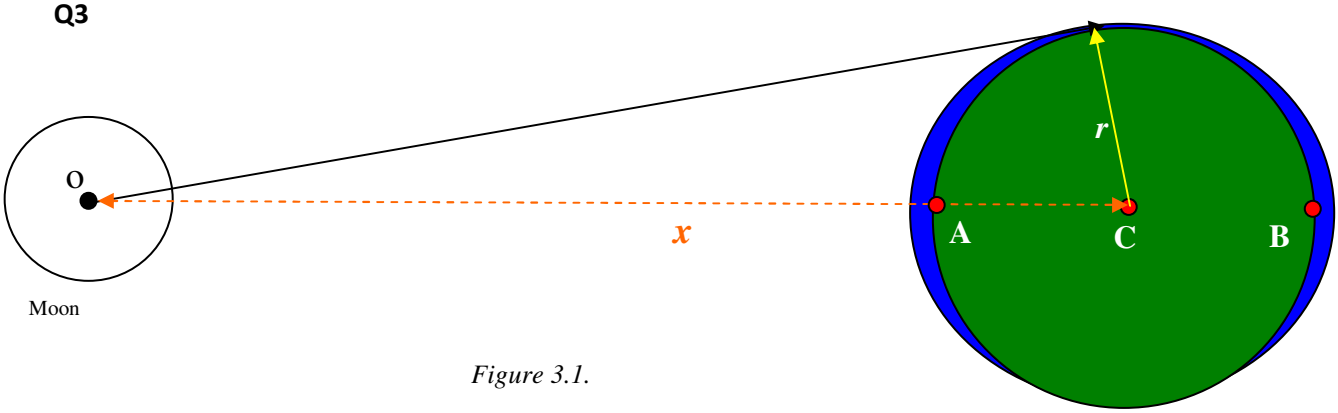


Figure 3.1.

(a) Figure 3.1 shows a diagram of the Earth and the Moon. Assume a very simple model that the whole smooth Earth is covered with a layer of water depth 750 m. Find an expression that relates the gravitational field due to the Moon at A and B (assume $r \ll x$). Hence give a reasoned estimate of the height of the tides at the equator. Ignore the effects of continents, ocean currents etc. Comment on your estimate and the assumptions you make.

(b) The Moon is slowly coming towards the Earth. The gravitational tidal effect on the Moon will become greater. The Roche limit is the value of the radius of an orbit at which the tidal effect on a body, in this case the Moon, will disrupt the body if it has no internal tensile strength, eg composed of sand or loose rock. What would be the Roche limit for a neutron star radius 10 km and mass about the mass of the Sun?

(c) The year is 3500 AD. Captain Amabo is steering his space ship Enterprise X11. He is searching for Dark Matter Asteroid VII which could be a hazard to space navigation. Dark matter interacts with ordinary matter through the exchange of gravitons that are the quanta of gravity. Gravitons were first detected in 2035 AD. The normal electromagnetic interaction does not react with dark matter. Enterprise X11 photon rocket engines are switched off. Design a very simple apparatus that he could carry that would warn him of the possible hazard. What is the nature of the hazard?

Q4

(a) In 1971 Leon Chua formulated the theory of the memristor. It is a passive two terminal device. He realised that he could relate the circles labelled *v, q, i, ϕ* diagrammatically, as shown in *Figure 4.1*. *Figure 4.1* is ***not*** a circuit diagram. The resistor in square 1 relates *v* and *i*. The capacitor in square 2 relates *q* and *v.* The inductor in square 3 relates ϕ and *i*. However, a device seems to be needed in square 4 to complete the symmetry. The name memristor was suggested for this device. In April 2008 HP Labs announced the development of a switching semiconductor memristor.

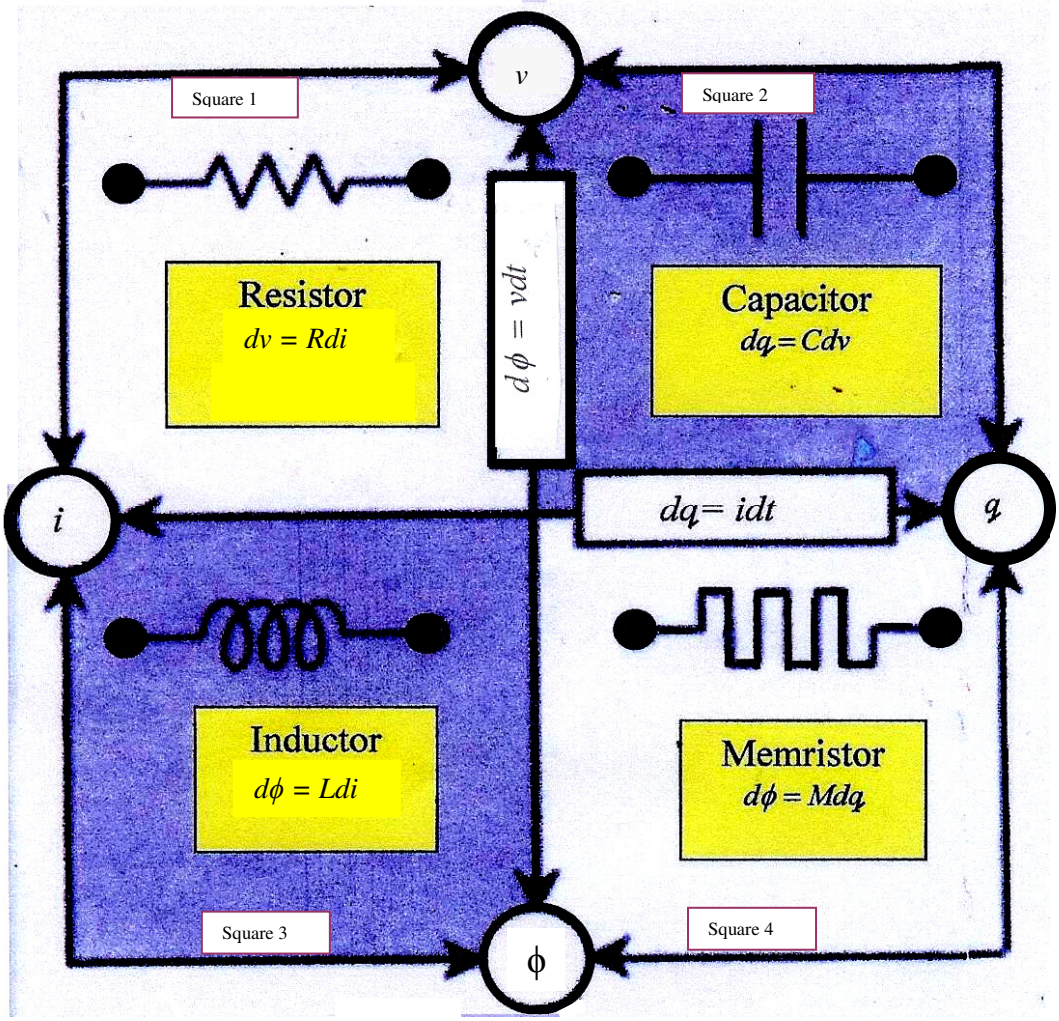


Figure 4.1

(i) Are the equations in *Figure.4.1* dimensionally consistent?

(ii) The team that first produced a memristor on a chip suggested that it could revolutionise the fabrication and use of computer memories. How?

(b)

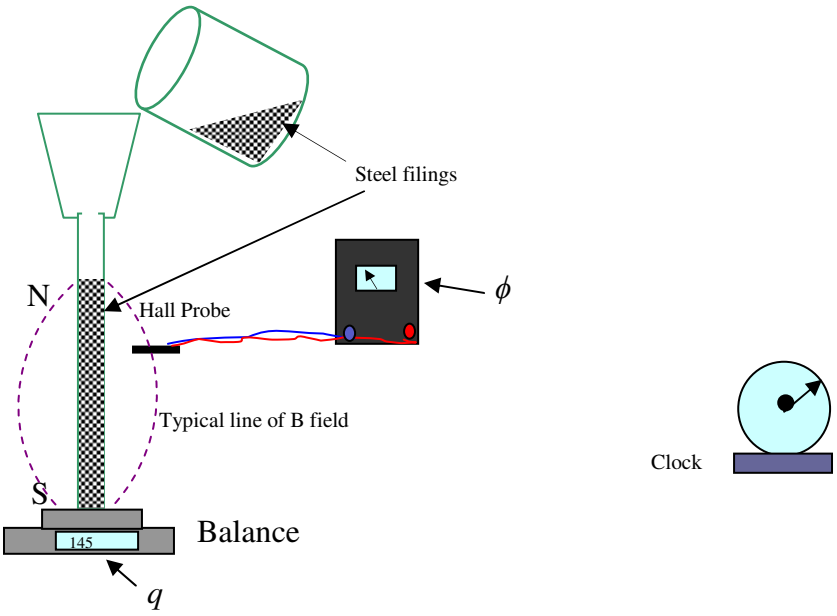


Figure 4.2.

A student has been given the task of making a practical analogue of a memristor. She thinks that she could make a bar magnet from lightly magnetised steel filings covered in a thin layer of slippery plastic placed in a suitable tube. Explain how this set up is an analogue of a memristor. Her idea is illustrated in *Figure 4.2*. Comment briefly on the suggested analogue, being careful to explain the physics involved.

(c)

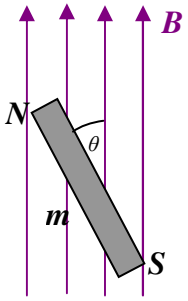


Figure 4.3

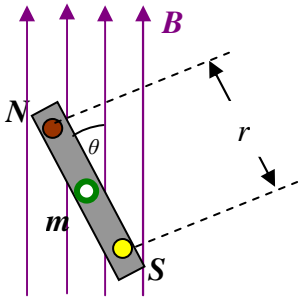


Figure 4.4

(i) A magnet will set itself along the field lines if it is able to rotate in the plane of the paper (*Figures 4.3).* There is a torque on the magnet due to the magnet's interaction with the Earth's field. The magnetic moment of a magnet, *m* is the maximum torque on it in a field of 1 T. Find an expression for the torque on the magnet illustrated in *Figure 4.3.*

(ii) It is possible to imagine a model of a magnet as a dipole where the pole strength is q_m. See *Figure. 4.4*. The poles are *r* apart. The force between two isolated magnetic poles is similar to that between two isolated charges i.e. where μ is the magnetic permeability of the intervening medium.

$$F = \frac{\mu q_{m1} q_{m2}}{4\pi r^2}$$

What is the relationship between q_m and *m*?

(d)

Figure 4.5

(i) *Figure 4.5* illustrates two "isolated" magnetic poles. The other two poles can be regarded as too far away to interact or contribute to the field. How can you find the direction of the field lines using a Hall probe?

(ii) Show that for a small isolated magnet, the magnetic field *B* at a large distance away *d* from the magnet will be proportional to $\frac{1}{d^3}$.

Q5

In the late 19th century the American student, Edwin Hall, was given the problem of observing the effect of a magnetic field on electrons travelling in a conductor. This is known as the Hall effect and the probe has been used in Q4.

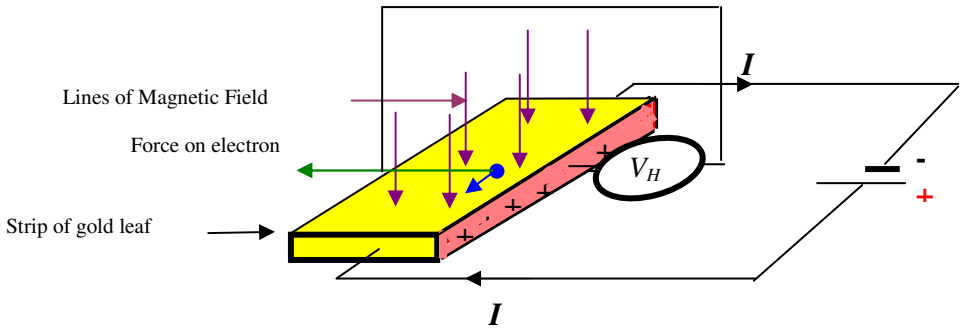


Figure 5.1

Figure 5.1. Illustrates the experiment. A current is passed through a strip of gold leaf and the current carriers (usually electrons) pass through the gold leaf. The current passes through the gold leaf in the direction shown. The magnetic field acts on the moving current carriers and these carriers are pulled to the left. One thin edge of the gold leaf becomes positive (coloured pink/grey), relative to the other side. The Hall voltage, V_H is the p.d. between points on the pink/grey face and the side opposite.

(i) The number density of the carriers is *n*, the cross sectional area of the strip is *a,* the charge on the current carrier (electrons) is *e*. Derive or write down an expression for the drift velocity, v_d in terms of *I,n,a,e.*

(ii) Draw a circuit diagram that shows a *practical* circuit that could measure the Hall effect in a strip of gold leaf. The effect is very small.

(iii) The charge carriers in semiconductors are fewer - therefore they move more rapidly for the same current density. How does this make the sensors based on Hall voltage more sensitive? In some materials the polarity of the voltage is reversed. Comment.

(iv) Measuring the thickness of the gold leaf is difficult. A student knows that when viewing a strong white light through a piece of gold leaf the light appears green - blue. He has also read that if 1 g of gold is beaten out as thin as possible it covers an area of 50 m^2. Are these facts consistent? Explain.

(v) The highest field available is 0.1 T. The length of the gold leaf is 40 mm, the width 10 mm and the current is 200 mA. What is the drift velocity of the free electrons (one per atom)? What would be the Hall voltage?

END OF PAPER.

Please attach the BPhO Round 2 cover sheet to the answer sheets and return to the following address by 6th February 2012:

A.G.Bagnall,
2 St Peter's Barn
West Knighton
Dorchester
Dorset
DT2 8PF

Note:
Please email bagnall@stpeters5.demon.co.uk giving details of date time etc of despatch.
Please use **Normal 1st Class** post and retain a photocopy of the script.