BPhO
British Physics Olympiad

BRITISH PHYSICS OLYMPIAD 2015-16

A2 Challenge

September/October 2015

Instructions

Time: 1 hour.

Questions: Answer ALL questions.

Marks: Total of 50 marks.

Solutions: These questions are about problem solving. Draw diagrams to get to grips with the questions. You must write down the questions in terms of symbols and equations, and try calculating quantities in order to work towards a solution.

In these questions you will need to explain your reasoning by showing your working. Even if you cannot complete the question, show how you have started your thinking; with ideas and, generally, by drawing a diagram.

Setting the paper: You are allowed any standard exam board data/formula sheet.

Important Constants

Speed of light	c	3.00×10^{8}	$\mathrm{m\ s^{-1}}$
Planck constant	h	6.63×10^{-34}	J s
Electronic charge	e	1.60×10^{-19}	C
Mass of electron	m_e	9.11×10^{-31}	kg
Gravitational constant	G	6.67×10^{-11}	$\mathrm{N\ m^{2}\ kg^{-2}}$
Acceleration of free fall	g	9.81	$\mathrm{m\ s^{-2}}$
Permittivity of a vacuum	ε_0	8.85×10^{-12}	$\mathrm{F\ m^{-1}}$
Avogadro constant	N_A	6.02×10^{23}	$\mathrm{mol^{-1}}$

Q1.

This question is about conservation laws relating to collisions.

a. An observer sees a spaceship of mass 1 tonne (1 x 10^3 kg) travelling to the right at 0.2 m s^{-1} towards a space-station of mass 2 tonne, which is travelling to the left at 0.1 m s^{-1}. The two space vehicles are on a direct course for the space ship to dock at the space-station.

   i) Draw a diagram of this situation, as seen by the observer.

   ii) What is the common velocity of the two vehicles once they have docked?

   iii) Where is the centre of mass of the ship and station system located, and what is the velocity of the centre of mass of the system, according to the observer?

   iv) What is the kinetic energy of the system before and after the docking?

   v) Repeat the procedure (i) to (iv) from the point of view of a space-walker floating along beside the space-station, before the docking has taken place.

   vi) Comment on the changes of kinetic energy from the point of view of the two observers.

b. *Newton's Cradle* is a well-known toy consisting of two equal hard steel balls mounted so that they make repeated, fully elastic, head-on collisions. The behaviour of this toy reflects the behavior of collisions between certain sub-atomic particles.

   i) Show that if one ball is still before the collision, the moving ball comes to rest after the impact, giving all of its momentum and kinetic energy to the previously stationary ball. (Notation: u is the initial speed, v_1, v_2 are speeds of the balls after the collision).

   ii) Comment on the relevance of this to a direct hit by a neutron on the nucleus of a hydrogen atom.

   iii) Now consider an oblique elastic collision between two equal masses, where one was originally at rest. Show that the final velocities of the two particles are perpendicular.

   iv) How might this be observed in the case of an oblique collision between a neutron and the nucleus of a hydrogen atom?

16 marks

Q2.

This question relates to changes occurring when a material is deformed.

a. A long, thin bar of metal is stretched elastically. Its initial dimensions are 1.0000 mm x 1.0000 mm x 1000.0 mm. After the stretching, these dimensions became 0.9997 mm x 0.9997 mm x 1001.0 mm. You will notice that the bar became thinner as well as elongated.

   i) Calculate the change in volume of the bar. Has it increased or decreased?

   ii) In what way is your conclusion consistent with there being the same amount of material in the bar both before and after the stretching?

   iii) The *Poisson Ratio* of a material is the ratio *lateral strain: longitudinal strain.* (strain is change in length/original length).
   Calculate the Poisson Ratio for this sample of metal.

b. Rubber has the property of deforming at virtually constant volume.

   i) A long sample of rubber with uniform square cross-section is stretched to a strain of 2%. By what proportion should the cross-sectional area reduce to maintain a constant volume?

   ii) Hence determine the percentage reduction in each side of the square cross-section.

   iii) From this calculate the Poisson Ratio for rubber.

6 marks

Q3.

This question considers a novel way of producing two-source interference (often called *Young's Fringes)* using visible light passing through a special prism.

a.

   i) Sketch the path of a ray of monochromatic light passing *symmetrically* through a glass prism (this is similar to the familiar experiment of Sir Isaac Newton producing a spectrum with a glass prism). Draw a large diagram with a ruler.

   ii) Mark the angle between the two faces of the prism at which refraction takes place as **A** (often known as the *refracting angle*). Extend the paths of the incident and emergent rays until they meet and mark the angle between them as **D**: this is the total angle through which the prism has turned the light ray (often known as the *angle of deviation*). Draw in the two normals. Mark all the angles on the diagram.

   Show for the *symmetrical* situation that

$$n = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin\left(\frac{A}{2}\right)} \qquad \text{where } n \text{ is the refractive index of the glass}$$

   iii) Show that this reduces to

   $D = (n-1)A$ for thin prisms (i.e. for small values of A and D)

b. Figure 3.1 shows the special double thin prism known as *Fresnel's bi-prism.*

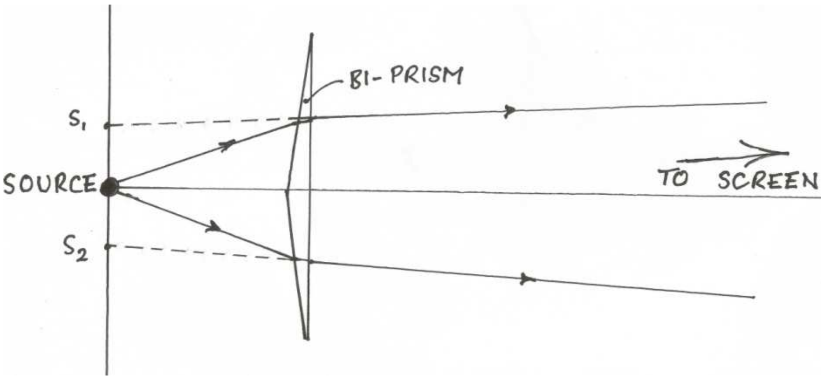

Figure 3.1

The light source is 0.1 m from the bi-prism. The refracting angle is 0.02 radians and the refractive index of the bi-prism is 1.50. Assume that the observation screen is sufficiently far away that the rays may be assumed to be approximately parallel.

Use the result in a(iii) above to calculate the deviation caused by each half of the bi-prism. (For such small angles you may assume that this is a symmetrical deviation)

i) Hence find the separation of the two virtual images, S_1 and S_2 of the source, which the bi-prism generates.

ii) These two images act as the two coherent sources for forming an interference pattern: explain why the light from the two images is coherent.

iii) Calculate the separation of fringes which this arrangement produces on a screen 1.9 m from the prism when the source emits light of wavelength 500 nm.

12 marks

Q4.

This question examines the consequences of connecting different power supplies in simple circuits, with some potentially surprising results.

An *ideal* electrical energy source provides a voltage, known as its *emf* (electro-motive force), but presents no resistance to the passage of current through itself. A *real* source also has an emf but also posseses *internal resistance,* for which reason a real source is often represented as in Figure 4.1.

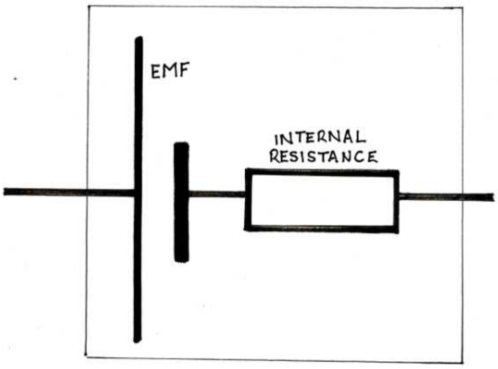

Figure 4.1

a. A real source with emf 3.0 V and internal resistance 1.0 Ω is connected to a resistor of resistance 2.0 Ω.

   i) What current flows in this circuit and also, what potential difference exists across the 2.0 Ω resistor?

   ii) Two such identical sources are now connected a shown in Figure 4.2.

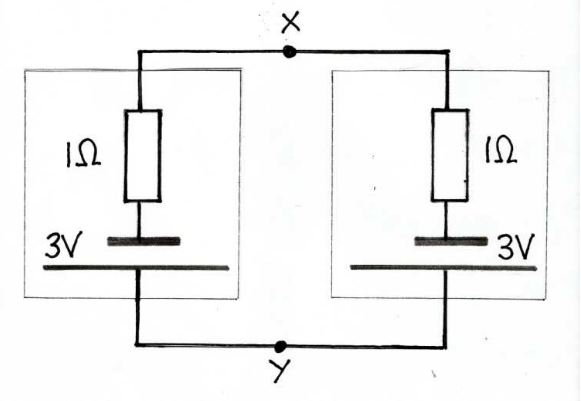

Figure 4.2

Calculate the current in the circuit.

   iii) A resistor of resistance 2.5 Ω is connected between the points X and Y. What current now flows in the 2.5 Ω resistor?

   iv) The resistor is now removed from XY and one of the sources is then reversed. Calculate the current in the circuit, and also the potential difference between X and Y.

b. We will now explore the effect of internal resistance in some practical situations. (**SAFETY WARNING: do not experiment with either of the scenarios described below**)

i) High voltage sources in school laboratories generate 5 kV and have a safety feature which adds an internal resistance of 10 MΩ. A person has a resistance of 10 kΩ and would find a current of 1 mA harmless while a current of 15 mA may prove fatal. Use this information to decide whether the safety feature on high voltage sources is effective.

ii) A car battery has an emf of 12 V and an internal resistance of 0.01 Ω . It can supply a current of 1.0 A for 60 hours.

1) How much energy is stored in the battery?

2) Plainly, a 12 V car battery will not give give a dangerous shock. However, it is extremely dangerous to connect the terminals of a car battery together. Calculate the current and the power output if the battery terminals are joined by a conductor of negligible resistance.

3) In what form and where does this energy appear, which makes this very dangerous?

11 marks

Q5.

This question looks at some practical consequences of the evaporation of liquids.

Placing a liquid in a vacuum (e.g. a leak from a space vehicle) forces it to evaporate and can lead to rapid cooling.

a. A water droplet at 10 ^{o}C escapes into space and begins to evaporate. Find its temperature when it has lost 1% of its mass. (To heat 1 kg of water by 1 ^{o}C requires 4.2 kJ of energy; to evaporate 1 kg of water requires 2.26 MJ of energy)

b. You come out of warm water after bathing. Use your result in (a) above to explain why you feel cold even if it is a very warm day.

c. Why is the result more marked if you are subjected to a draught?

d. Why does applying a volatile liquid, such as ethanol, to your hand feel particularly cold?

5 marks

END OF PAPER