# British Physics Olympiad 2012-2013

## BPhO Round 2

## 4th February 2013

## Instructions

**Time**: 3 hours (approximately 36 minutes on each question).

**Questions**: All five questions should be attempted. A standard formula sheet may be used.

**Marks**: All questions carry 20 marks.

| | | | |
|---|---|---|---|
| Mass of a Neutron star | $M_{ns}$ | $6\times10^{30}$ | kg |
| Radius of a Neutron star | $R_{ns}$ | $10^{4}$ | m |
| Mass of the Sun | $M_{sun}$ | $2\times10^{30}$ | kg |
| Radius of the Sun | $R_{sun}$ | $7\times10^{8}$ | m |
| Mass of Jupiter | $M_{Jup}$ | $1.90\times10^{27}$ | kg |
| Mass of Earth | $M_{Earth}$ | $5.97\times10^{24}$ | kg |
| Radius of Jupiter | $R_{Jup}$ | $7.15\times10^{4}$ | km |
| Radius of Earth | $R_{Earth}$ | $6.4\times10^{3}$ | km |
| Speed of light | $c$ | $3\times10^{8}$ | m $s^{-1}$ |
| Stefan - Boltzmann constant | $\sigma$ | $5.67\times10^{8}$ | W $m^{-2}$ $K^{-4}$ |
| Avogadro Number | $N$ | $6.02\times10^{23}$ | $mol^{-1}$ |
| Relative Atomic Mass of Iron | | 55.8 | |
| Relative Atomic Mass of Copper | | 63.5 | |
| Specific Heat Capacity of Copper | | 385 | J $kg^{-1}$ $K^{-1}$ |
| Density of copper | | $8.40\times10^{3}$ | kg $m^{-3}$ |
| The Planck Constant | $h$ | $6.62\times10^{-34}$ | $m^{2}$ kg $s^{-1}$ |
| Earth - Sun distance | $R_{ES}$ | $150\times10^{6}$ | km |
| Jupiter - Sun distance | $R_{JS}$ | $778\times10^{6}$ | km |
| Gravitational Constant | $G$ | $6.67\times10^{-11}$ | $m^{3}$ $kg^{-1}$ $s^{-2}$ |

**1.**

Observations show that the speed of light in a vacuum is always the same whatever the speed of the source relative to that of the observer.

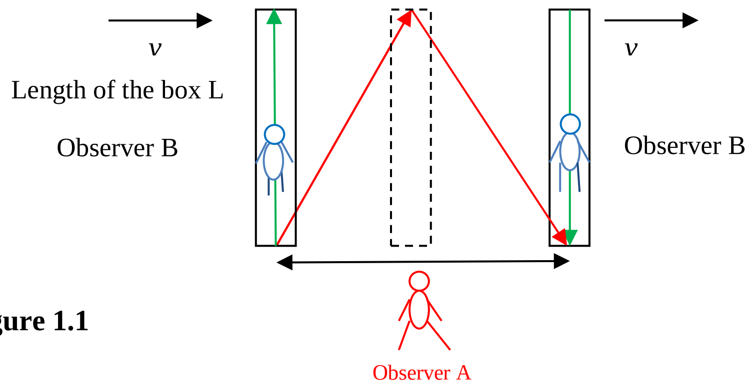



**Figure 1.1**

a) Light, illustrated by green arrows, bounces up and down in the box that has perfect mirrors at each end. Observer B is in the box and Observer A is outside the box. The box is observed by A to be moving past at a speed of $v$.

(i) How far does Observer B think the light has travelled?

(ii) How far does Observer A think the light has travelled?

(iii) How long does Observer B think the light takes to travel this distance?

(iv) How long does Observer A think the light takes to travel this distance?

b) Two copper wires carry a current of $I$ amps, Figure 1.2. The wires are 1mm in diameter and you may assume that there is one free electron per atom.

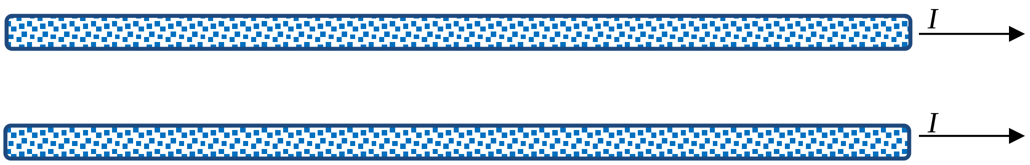



**Figure 1.2**

Find the speed at which the electrons drift down the wire (ignore thermal effects). Use a semi-quantitative argument to show that there will be a force between the wires when a current $I$ flows in each wire - without bringing in the concept of magnetism.

**2.**

**Figure 2.1**

The photo, Figure 2.1, was taken at Broadhaven, Pembrokeshire. The road that is damaged crossed a small stream flowing into the sea. The tidal range is about 8 m. The previous day at another location a wave hitting a harbour wall was observed to be producing a splash that rose 6 m high.

(i) Calculate the speed at which the water was moving vertically upwards when it was about 3.5 m above the normal surface of the stream – that is about the level of the under surface of the bridge. Assume that an unrestricted splash would have been 6 m high.

(ii) Find the force on a square stone in the under surface of the bridge that is 0.5 m × 0.5 m and with a thickness ≈ 100 mm as illustrated in Figure 2.2.

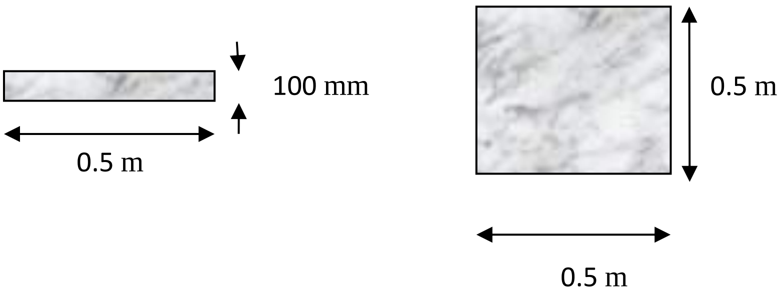



**Figure 2.2**

(iii) The density of the stone is 4000 kg $m^{-3}$. What is the lowest speed of the water splash at which you might expect the bridge to fail?

**3.**

Most heavy vehicles are equipped with retarders that have a copper disc on a rotating axle. An electromagnet produces a magnetic field and this produces a force on the moving disc. .

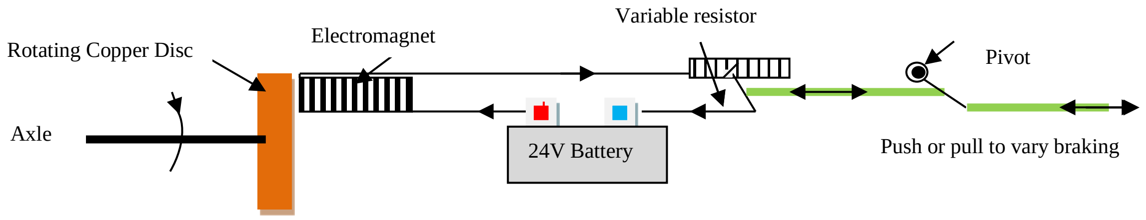



**Figure 3.1**

The gradient of the road is 20% (take this as the height lost/distance gone). The truck has a mass of 10 tonnes. The diameter of the copper disc is 0.5 m, the thickness of the disc 15 mm. Ignore other forms of braking such as engine braking, normal disc brakes, air resistance, etc.

(i) Find an expression that would give the rate of heat generated in the copper disc.

(ii) Find the initial rate of rise of temperature of the copper disc. The electromagnetic braking is designed to allow the lorry to descend a slope of 20% at a steady 5 $ms^{-1}$ without using engine braking or normal friction brakes.

(iii) Estimate the final temperature of the disc assuming that the heat is lost only through radiation. Stefan's law states that the power radiated by a black body is $A\sigma T^4$ where A is the area of the radiating body and $\sigma$ is the Stefan-Boltzmann constant. You may assume that the disc approximates to a black body in this case.

**4.**

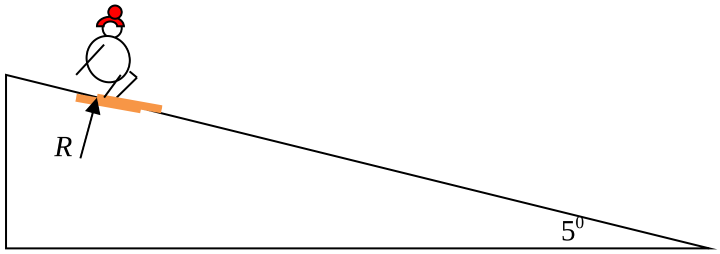



**Figure 4.1**

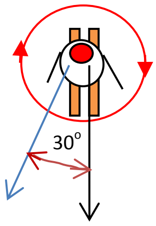


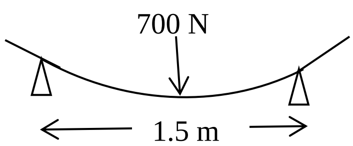

**Figure 4.2**

a) Figure 4.1 shows a skier, mass 70 kg, going down a snow slope of $5^o$ that is covered in firm hard snow, temperature $-4^o$ C. His skis are initially parallel, close together and going down the line of steepest slope. He intends to go down the slope in a series of sweeping curves. His first turn is $30^o$ to the steepest slope and his next turn is through $60^o$. You are asked to answer the following questions as quantitatively as possible using estimated numerical values where appropriate. *Ski jargon is not appropriate!*

(i) How can he reduce the normal reaction *R*? His mass is 70 kg. Give a numerical estimate of the maximum percentage of *R* it would be reasonable to achieve.

(ii) How can he rotate his skis in a clockwise direction? How can he stop the rotation?

b) Another way of turning (carving) depends on the skis bending to form a curve which enables the skier to follow a curved path. He decides to test the stiffness of the skis Figure 4.3. He uses a weight of 700 N.




Length of ski is 1.80 m

**Figure 4.3**

(i) The skis are tested using the setup illustrated in Figure 4.3. A force of 700 N deflects the centre of the ski 50 mm. What speed should the skier be going to achieve a turn with a radius of curvature of 25 m? Comment.

(ii) Illustrate your solution with a force diagram. Is this the only consideration that concerns the skier? Ignore the presence of other skiers!

**5.**

a) A particle of electromagnetic radiation is called a photon. A photon has an energy of $hf$ where $h$ is Planck's constant. Write down an expression for the wavelength of the photon if it is emitted from a body moving away from the observer at a speed of $u$ where $u$ is much less than $c$. However, Einstein's theory of general relativity predicts another effect. On leaving the star the photon gains potential energy due to the star's gravitational field.
Derive an expression that gives the change in wavelength due to this gravitational effect when light of frequency $f$ leaves a star of mass $M$, radius $R$. For the purposes of this derivation you can assume that a photon has a fictional mass of $m$ that will (should!) disappear from your final equation.

b) Among the animals that appear in the zoo of the Universe there are black holes and neutron stars. The mass of each of these is often the order of the mass of the Sun. The radius of a neutron star is about 10 km and a certain neutron star rotates at about $100\pi\ s^{-1}$.
Calculate the ratio of the polar diameter to the equatorial diameter for a typical neutron star. Assume that liquid or solid neutron material is incompressible. How do we know that it is rotating at this frequency?

c) Why are space rockets launched from positions near the equator? In order to launch a space probe out of the solar system, it is decided to send the probe close to Jupiter. Explain why this route reduces the fuel needed.