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# BRITISH PHYSICS OLYMPIAD

## 2010 AS Competition Paper

Time allowed: 1 hour

Total marks available: 50

Attempt all questions.

Write your answers on this question paper.

Allow no more than 15 minutes for Section A.

You may use any calculator.

You may use any public examination formula booklet.

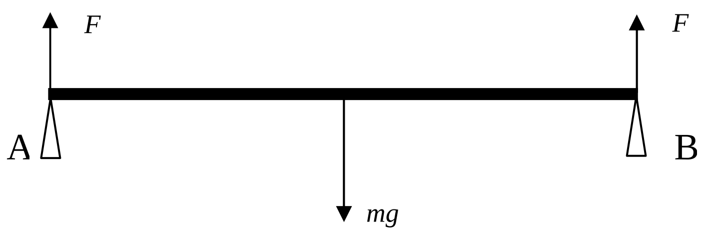
Marks allocated for each question are shown in brackets on the right.

Assume the gravitational field strength has a value of **g = 9.8 N/kg**

**Section A: Multiple Choice Answers**

Circle the correct answer to each question. There is only one correct answer.
Each question is worth 1 mark.

**1.** A uniform beam of mass *m* is rests symmetrically on two supports A and B. The forces acting on the beam are shown.
If support B is slid towards the left, how does the force provided by support A change?




**A.** It is always equal to the force provided by B

**B.** It remains as *F*

**C.** It becomes greater than *F*

**D.** It becomes less than *F*

**2.** A small object is dropped from the top of a building and falls to the ground. As it falls, accelerating due to gravity, it passes a window. If it has speed $v_1$ at the top of the window, and speed $v_2$ at the bottom of the window, at what point does it have a speed $(v_1 + v_2)/2$ ?
Neglect the effect of air resistance.

**A.** It depends on the height of the window or its distance from the top of the building

**B.** Above the centre point of the window

**C.** Below the centre point of the window

**D.** At the centre point of the window

**3.** A two litre sealed container is filled with air at atmospheric pressure. It is connected to a vacuum pump which can pump air at a flow rate that is proportional to the difference in pressure within the container to the pressure outside. This tells us that the pressure drops exponentially with time. If it takes 20 seconds for the pressure in the container to halve, how long would it take to reduce the pressure in a five litre container from atmospheric pressure to $1/8^{\text{th}}$ of atmospheric pressure

**A.** 48 s

**B.** 150 s

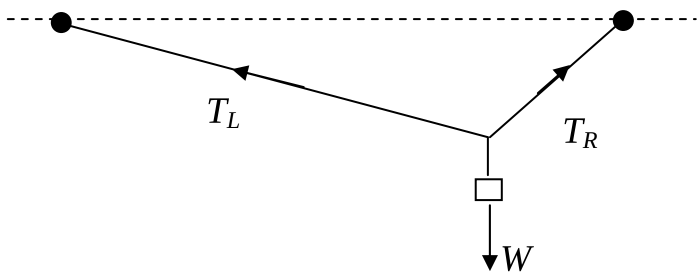
**C.** 200 s

**D.** 250 s

**4.** The formula for kinetic energy is the same whatever the system of units that are used. In the SI system, the units are metres, kilograms, seconds and joules. In the cgs system, the corresponding units are centimetres, grams, seconds and ergs. The number of ergs in a joule is:

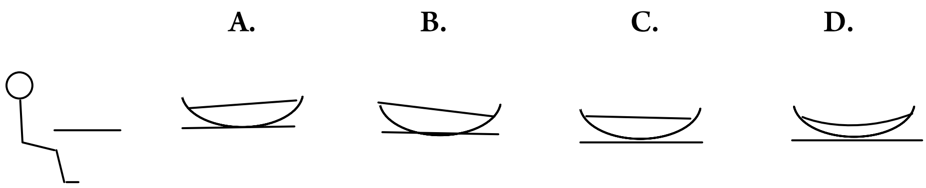
**A.** $10^{-5}$ **B.** 1 **C.** $10^{5}$ **D.** $10^{7}$

**5.** A weight $W$ is hung from a wire stretched between two fixed supports as shown. The tension in the wire to the left of the weight is $T_L$ and that to the right of the weight is $T_R$. Which of the following is correct?




**A.** $T_L + T_R = W$ **B.** $T_L = T_R$ **C.** $T_L > T_R$ **D.** $T_R > T_L$

**6.** A passenger, sitting on a train and facing the engine at the front of the train, has a bowl of thin soup on the table in front of him. The train decelerates as it enters a station. Which sketch best represents the level of the soup in the bowl?




**7.** In the LEP accelerator at CERN, before the new LHC was constructed in the same tunnel, an electron could be accelerated until it reached a total energy of about 400 GeV ($400 \times 10^9$ eV). Estimate which of the examples below has a similar amount of kinetic energy?

$$e = 1.6 \times 10^{-19}\ \text{C}$$

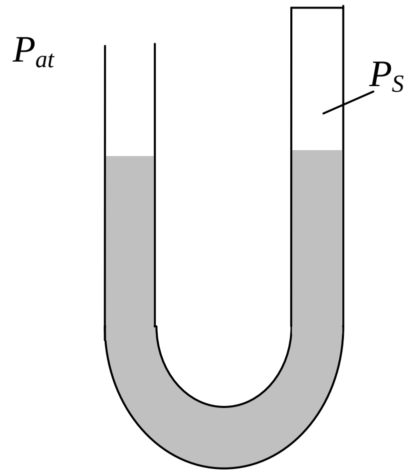
**A.** An oxygen molecule moving at 500 m $s^{-1}$ (as in air at room temperature)

**B.** A snail crawling at 2 mm $s^{-1}$

**C.** A house brick that has fallen 100 m

**D.** An airliner cruising at 500 km $hr^{-1}$

**8.** A glass U-tube is sealed at one end with the other end being open to the atmosphere. It contains mercury so that the levels in the two sides of the U-tube are the same. The pressure above the mercury in the sealed end is $P_S$ and the pressure of the atmosphere is $P_{at}$. What can be said about the pressures in this system?




**A.** $P_S = P_{at}$

**B.** The pressure at all points in the mercury is the same

**C.** $P_S > P_{at}$

**D.** $P_S < P_{at}$

**9.** The best estimate of the mass of one cubic metre of air at atmospheric pressure is:

**A.** 1 mg

**B.** 1 g

**C.** 1 kg

**D.** 1000 kg

**10.** A long uniform metal plate has a square hole cut in it. The plate is uniformly heated so that it expands a small amount. What is a correct statement about the hole now?

**A.** It is still square

**B.** It is rectangular in shape

**C.** It has decreased in area

**D.** It has remained the same area

**Section B: Written Answers**

**11.** An archaeologist at an excavation discovers a crown that looks like gold. It has a mass of 546 g and a volume of 34.6 $cm^3$. However, chemical analysis shows that the crown consists of a mixture of gold and silver. Unfortunately the analysis is unable to give the proportions without removing a sample. The problem is to find the mass of gold in the crown. We assume that the volume of the crown is equal to the initial volumes of gold and silver of which it is composed.

Density of gold, $\rho_g = 19.3$ g $cm^{-3}$
Density of silver, $\rho_s = 10.5$ g $cm^{-3}$

a) Write down an equation relating the masses $m_g$ and $m_s$ of gold and silver in the crown and an equation for the corresponding volumes $V_g$ and $V_s$.

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b) Write down an equation for the total mass in terms of the volumes $V_g$, $V_s$ and densities $\rho_g$, $\rho_s$ of the gold and silver in the crown.

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c) In the equation from (b) substitute for $V_s$ and then substitute for $V_g$ to obtain a relation between $\rho_g$, $\rho_s$ and $m_g$.

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d) Determine the value of the mass of gold, $m_g$.

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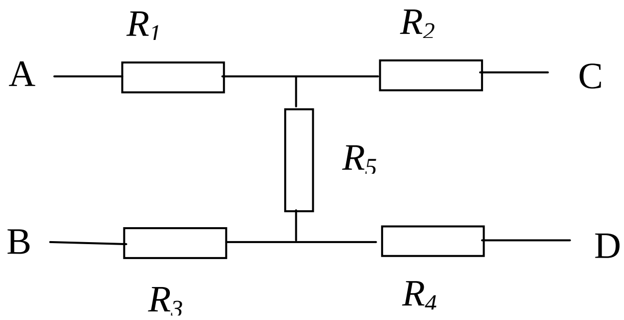
**12.** A combination of resistors shown below represents a pair of transmission lines with a fault in the insulation between them. The wires have a uniform resistance, but do not have the same resistance as each other. The following procedure is used to find the value of the resistance $R_5$.




A potential difference of 1.5 V is connected in turn across various points in the arrangement.

With 1.5 V applied across terminals AC a current of 37.5 mA flows

With 1.5 V applied across terminals BD a current of 25 mA flows

With 1.5 V applied across terminals AB a current of 30 mA flows

With 1.5 V applied across terminals CD a current of 15 mA flows

a) Write down four equations relating the potential difference, the resistor values and the currents.

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b) Determine the value of resistor $R_5$.

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c) If the ends C and D are connected together, what would be the resistance measured between A and B?

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d) If the length AC (and also BD) is 60 metres of resistive wire, how far from A (or C) does the fault occur?

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**13.** Waves on the open sea, known as gravity waves in order to distinguish them from ripples on a pond, have a speed $v$ that depends upon the wavelength $\lambda$ and the depth of the sea, $h$.

In **deep water**, $h >> \lambda$ and the speed $v$ is independent of $h$, but does depend upon $\lambda$.

$$v = \sqrt{\frac{g\lambda}{2\pi}}$$

In **shallow water**, $h << \lambda$, and the speed $v$ is independent of $\lambda$, but does depend upon $h$.

$$v = \sqrt{gh}$$

a) For a ship in **deep water**, the motion of the ship creates a wave such that the faster the speed the longer the wavelength. At some speed, known as the hull speed, $v_{hull}$, the wavelength becomes equal to the length of the ship $L$, as shown below. It is then very difficult for the ship to increase its speed as it has to climb the wave at the bow.

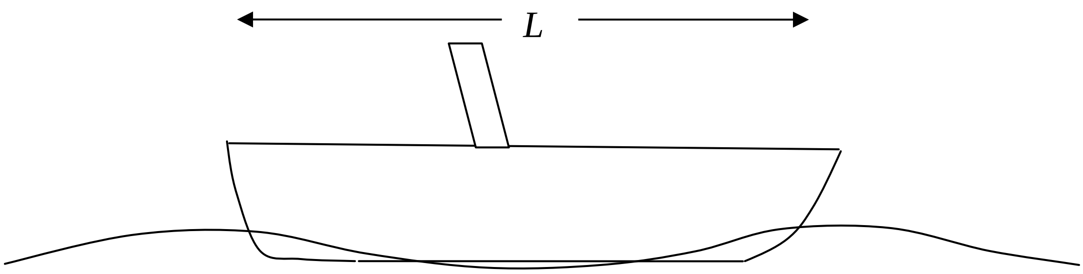


Figure 1

Show that $v_{hull} = 1.2\, L^{½}$

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b) The formula $v_{hull} = 1.2\, L^{½}$ only works when $L$ is measured in metres. Explain why.

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c) Show that for deep water waves, $v = \frac{g}{2\pi}T$ where $T$ is the period of the wave.

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d) A Tsunami (a wave produced as the result of an earthquake) on the ocean has an immense wavelength of 80 km (so the **shallow water** situation applies). Calculate the speed of the wave when the depth of the ocean is 4.7 km, and also when it enters the coastal shallows where the depth is 10 m.

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e) The power $P$ associated with a Tsunami wave progressing across the ocean is proportional to the speed of the wave, $v$ (the speed of energy flow), and the square of the amplitude $A$. The power flowing past a point is constant (otherwise energy would accumulate). Show that for the Tsunami, $A$ is proportional to $h^{-1/4}$.

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f) If the amplitude of the wave is 35 cm on the open ocean where the depth is 4.7 km, calculate the amplitude of the wave when the depth of the water is 10 metres.

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g) If the distant from the source of the Tsunami is only a few thousand kilometres then the Earth can be considered as a flat surface. However, if the distance from the source is very great then the curvature of the surface of the Earth will focus the waves. The intensity of the wave varies as $\frac{1}{\sin\left(\frac{r}{R}\right)}$ where $r$ is the distance from the source and $R$ is the radius of the Earth. At what distance from the source will the wave intensity begin to increase due to focusing?

$$R = 6{,}400 \text{ km}$$

Note that in $\sin(r/R)$ the term $r/R$ will give the angle in radians.

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**14.** Light travelling at speed *c* behaves both as a particle (a photon) and a wave. As a particle, the particle energy, *E*, is given by $E = hf$ where *h* is Planck's constant and *f* is the frequency of light. As a wave it is described by a frequency *f* and wavelength $\lambda$.

In figure 2 below, a thick walled insulating sphere, of internal radius 20 cm, behaves like the inside of a furnace. Negligible heat escapes through the walls when it is hot, but after a long period of time the 24 W heater at the centre has warmed the internal wall to such an extent that it is at equilibrium, having reached the same temperature as the heater. There is a small observation hole in the wall of the furnace through which radiation escapes.

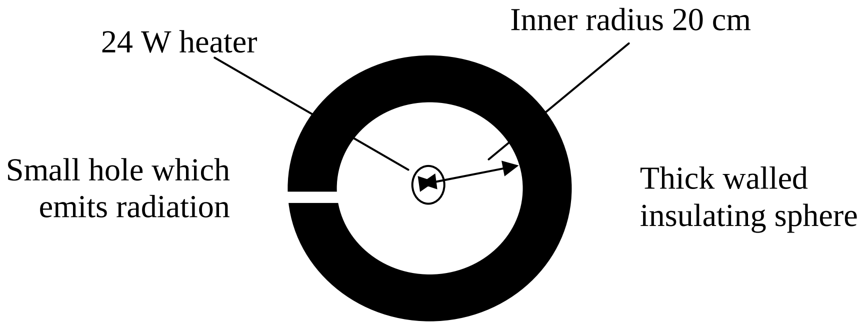


Figure 2

speed of light $c = 3.0 \times 10^{8}$ m s$^{-1}$

volume of a sphere $= \frac{4}{3}\pi r^3$

a) When the final temperature is achieved, someone looking through the observation hole can see the heater and one eighth of the surface area of the furnace. How much power is emitted from the observation hole? Explain your answer.

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b) If the observation hole is closed for a short time, what change will occur inside the furnace?

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c) A photon emitted from the heater is absorbed by the wall. Determine the time between emission and absorption of a photon.

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d) If the heater emits radiation for the time period obtained in part (c), calculate the amount of this energy.

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e) Calculate the number $n$ of photons emitted in this time if we assume that they have the average wavelength of 2900 x $10^{-9}$ m.

Planck's constant $h = 6.6 \times 10^{-34}$ Js

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f) In fact there are several orders of magnitude more photons in the furnace because the walls, with their large surface area, also radiate. The photons exert a pressure $P$ on the furnace walls, which is given by $P = \frac{1}{3}U$, where $U$ is the energy per unit volume of the radiation in the furnace. When it is at a steady temperature, the total radiation energy in the furnace is 2.5 x $10^{-5}$ J. Calculate the pressure $P$ on the walls.

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g) If we used the energy emitted by the heater in a short time as in part (d), estimate how many orders of magnitude greater is the pressure of radiation in the furnace than that pressure which corresponds to the amount of energy in part (d).

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[**End of Questions**]