British Physics Olympiad 2012/2013

A2 Challenge (previously Paper 1)

September/October 2012

Answer all questions

Allow 1 hour
Total 50 marks

$g = 9.8 \text{ m s}^{-2}$

$c = 3.0 \times 10^{8} \text{ m s}^{-1}$

speed of sound in air = 330 m s^{-1}

These questions are about problem solving. You must write down the question in terms of symbols and equations, and try calculating quantities in order to work towards a solution.

In these questions you will need to show 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.

1. Two non-reacting liquids of equal mass, m, are mixed together. One of the liquids has a density of 800 kg m^{-3} and the other has a density of 1200 kg m^{-3}. What is the density of the mixture?

(5 marks)

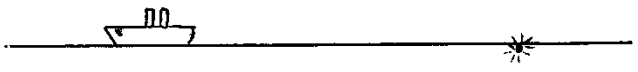
2. Einstein produced a famous equation giving an equivalence between mass and energy ($E = mc^2$, with m being the mass and c being the speed of light). Energy converted in a reaction can be considered as a loss of mass.
Electrical energy is often measured in kW hours, and one joule is equivalent to one "watt second" (1 J = 1 W s).

   a. How many joules are equivalent to one kW hour?

   b. The core of a nuclear reactor converts nuclear energy into heat energy and then that is converted into electrical energy. If the conversion from heat energy to electrical energy is 35% efficient, and a reactor is able to produce 15 x 10^9 kW hours of electrical energy in one year, then what is the mass loss per second of the reactor core due to nuclear reactions?

(8 marks)

3. An ocean survey vessel lays an explosive charge just beneath the surface of the sea. When the charge is a safe distance astern, it is detonated by a radio signal at time $t = 0$.



The sound of the explosion reaches the vessel by three routes at the times given:

(i) Through the sea along a straight horizontal path , at time t = 650 ms
(ii) Through the air at time t = 3.05 s
(iii) Through the sea by reflecting off the ocean floor, at time t = 3.26 s

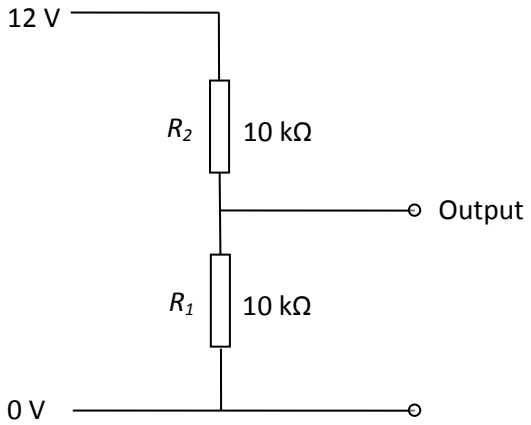
Calculate:

a. The speed of sound in sea water

b. The depth of the ocean at the survey site

(11 marks)

4. A potential divider consists of two resistors connected in series across a 12 V power supply of negligible internal resistance. It is designed to produce an output of 6.00 V. The power supply maintains a potential difference across the potential divider of 12 V exactly, and the two 10 kΩ resistors R_1 and R_2 each have a tolerance of ±5%.



a. What is the maximum discrepancy from 6.00 V which may be expected at the output?
b. The output is found to be 6.10 V Assume that R_1 is exactly 10 kΩ. What resistor connected in parallel with R_1, will change the output to 6.00 V?

(10 marks)

5. Two steel guitar strings B and G are of equal length, but their tensions (T_B and T_G) and diameters (d_B and d_G) are both in the ratio 1:1.56. When a wire of diameter d is under tension T its vibrational frequency, f, is proportional to $\sqrt{T}$ and to$1/d$.

When the B string is plucked a note of frequency 245 Hz is heard. What frequency will be produced when the G string is plucked?

(8 marks)

6. In the Large Hadron Collider at CERN, the charged particles (protons) are accelerated up to a speed approaching that of light and orbit around the 27 km circumference in a vacuum pipe. When a charged particle is accelerated, it loses energy by a process called synchrotron radiation. The charged particle in the LHC travels in a circular orbit and radiates energy due to the acceleration resulting from its circular motion. This energy loss limits the maximum energy of the LHC. The more energy that is put into the beam, the more energy is radiated away by the beam. The LHC maximum energy has been decided such that no more than 5% of the beam energy, *E*, is lost per orbit.

   The radiation energy lost per orbit, *R*, is proportional to the energy of the beam, *E*.

   $$R \propto E^4$$

   or alternatively $R = kE^4$ where *k* is a constant.

   The accelerator is operated at energy *E*. If *E* is then increased by 1%, by how much is the radiation, R increased?

   You may find it useful to know $(1 + x)^n \approx 1 + nx \quad \text{for } x \ll 1$

   (8 marks)