British Physics Olympiad 2013-2014

BPhO Round 2

27th January 2014

Instructions

Time: 3 hours (approximately 30 minutes on each question).

Questions: All six questions should be attempted.

Marks: All questions carry 20 marks.

Instructions: To accommodate students sitting the paper at different times, please do not discuss any aspect of the paper on the internet until 8 am Saturday 1st February.

Solutions: Answers and calculations are to be written on loose paper or examination booklets. Graph paper and formula sheets should also be made available. Students should ensure their name and school is clearly written on all answer sheets.

Further information and the International Physics Olympiad

*In late February, fifteen students eligible to represent the UK at the International Physics Olympiad (IPhO) will be invited to attend the training session to be held in the Physics Department at the University of Oxford, (**Tuesday 8th –Friday 11th April 2014**). Problem solving skills will be developed, practical skills enhanced, as well as some coverage of new material (Thermodynamics, Relativity, etc.). At the Training Camp a practical exam is sat as well as a short Theory Paper. Five students (and one to three reserves) will be selected for further training. There may be a weekend Training Camp in Cambridge in May (tbc) as well as the training camp at Trinity College, Cambridge (Sunday 29th June – Friday 4th July), followed by a short Oxford Training Camp (**Tues/Wed 8th/9th July to Friday 11th July**). The IPhO this year will be held in Astana, Kazakhstan, from **Sunday 13th July to Monday 21st July 2014**.*

Important constants

Speed of light in free space	c	3.00×10^{8} m s^{-1}
Elementary charge	e	1.60×10^{-19} C
Acceleration of free fall at Earth's surface	g	9.81 m s^{-2}
Permeability of free space	μ_o	$4\pi \times 10^{-7}$ H m^{-1}
Refractive index of water	n_w	1.33
Mass of a neutron	m_n	1.67×10^{-27} kg
Mass of a proton	m_p	1.67×10^{-27} kg
Boltzmann constant	k	1.38×10^{-23} J K^{-1}
Planck's constant	h	6.62×10^{-34} J s
Radius of the Earth	R_E	6.44×10^{3} km
Mass of the Sun	M_s	2.0×10^{30} kg
Distance of Jupiter from the Sun	$R_{Jupiter}$	78×10^{7} km
Mass of the Earth	M_E	6.0×10^{24} kg
Mass of Jupiter	M_J	1.9×10^{27} kg
Orbital period of Jupiter	T_J	4332 Earth days
Gravitational constant	G	6.67×10^{-11} m^{3} $kg^{-1}s^{-2}$
Density of air at ground level	ρ_{air}	1.20 kg m^{-3}
Density of concrete	$\rho_{concrete}$	3000 kg m^{-3}

N.B these figures are kept to a small number of significant figures for simplicity.

1.

Explain or comment on the following. More marks will be awarded for numerate or algebraic solutions where possible. Estimate quantities that you may need if these are not given.

i) Light hitting a single small hole will spread out.

ii) Why do you think that stars appear to twinkle to the naked eye when planets do not?

iii) Figures 1.1 and 1.2 show a comet with its tail. On the original photo the tail is so transparent that stars can be seen through the tail. Why does the comet's tail always point away from the sun? Why are there two tails, as seen in Figure 1.2? Explain what orbit the comet might follow.

iv) It seems odd that the planets' orbits round the Sun are nearly circular. Why do you think this is?

Figure 1.1

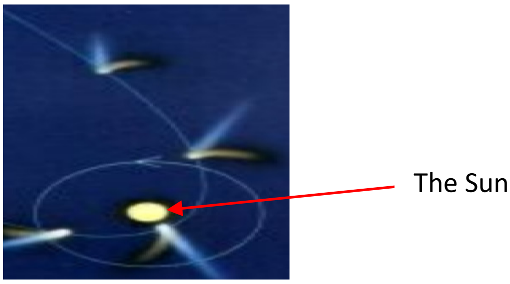

Figure 1.2

2.

It can be shown that a square wave can be represented by a sum of sine waves as given by the formula below

$$v = v_0 \sin\omega_o t + v_1 \sin\omega_1 t + v_2 \sin\omega_2 t + v_3 \sin\omega_3 t + \ldots..$$

Solar cells have an output that is dc. The pd across a cell depends on the incident radiation and the efficiency of the solar cells – Hubble telescope cells have an efficiency of about 30% in full sunlight. Solar cells for use on buildings etc. normally have an efficiency of about 15%. The dc power from the solar cells has to be transmitted to the mains which is 240V ac. At your disposal you have electronic black boxes. A possible solution is sketched out in Figure 2.1 below.

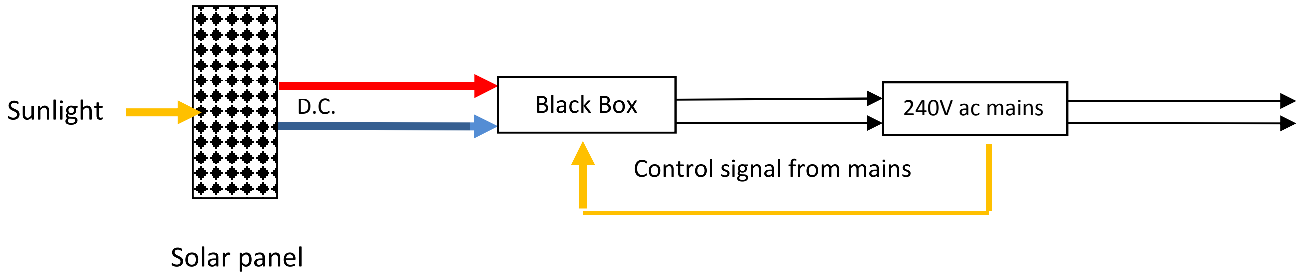

Figure 2.1

What is the black box for? Suggest components for the black box.

Some electrical energy may be lost as heat. How can you maximise the efficiency of the electrical energy transfer from the solar panels to the 240 V ac of the mains?

Explain why electrical energy is transferred by the grid using three or four wires.

It has been suggested that one way of storing electrical energy would be to store it in a rotating flywheel. A simple flywheel should store electrical energy from a 1MW power supply for 20 minutes. Suggest a design for this flywheel. *Marks are awarded for the detail of the design.*

3.

Calculate the approximate speed of Nitrogen molecules at a temperature of 20^{o} C.

Calculate the height at which the density of the Nitrogen molecules becomes one per cent of the pressure at ground level. It has been suggested that if a plane achieved a suborbital flight to Australia then a great deal of fuel could be saved. Estimate the energy needed to reach a suitable height so that the resistance of the air would be very small.

The "Dreamliner" has a mass of 2.27×10^5 kg.

4.

It has been reported that the wind speed reached 200 mph (90 ms^{-1}) in the Philippines. This is capable of toppling walls.

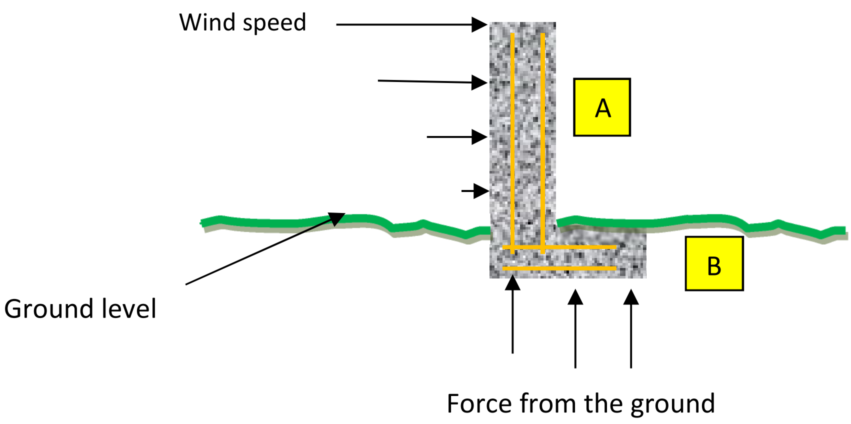

Figure 4.1

A concrete wall is made from two sections A and B. Section A is 2 m high and section B is 1.3 m long. The thickness of the concrete is 0.7 m. The cross section is made of concrete. The orange lines within the concrete show the position of reinforcing steel bars with a twisted cross section of rather rusty steel. Why are these steel bars embedded in the wall? It may be assumed that there is a linear increase in wind speed with height.

i) How does the pressure of the wind vary with the height of the wall? Hence, or otherwise, find how the pressure on the ground varies with position. Hence estimate what wind speed is likely to topple the wall.

ii) How else could you help make the wall more stable?

5.

Imagine that you are an observer on a planet of a nearby star such as Proximae Centauri (if it has one). You might notice that our Sun seems to wobble slightly with a somewhat complex wobble. This observed wobble has been used to detect planets round other stars.

i) What is the wobble due to?

ii) Using the data provided find the maximum speed of the wobble.

iii) What other method might be used to detect a planet orbiting a distant star?

6.

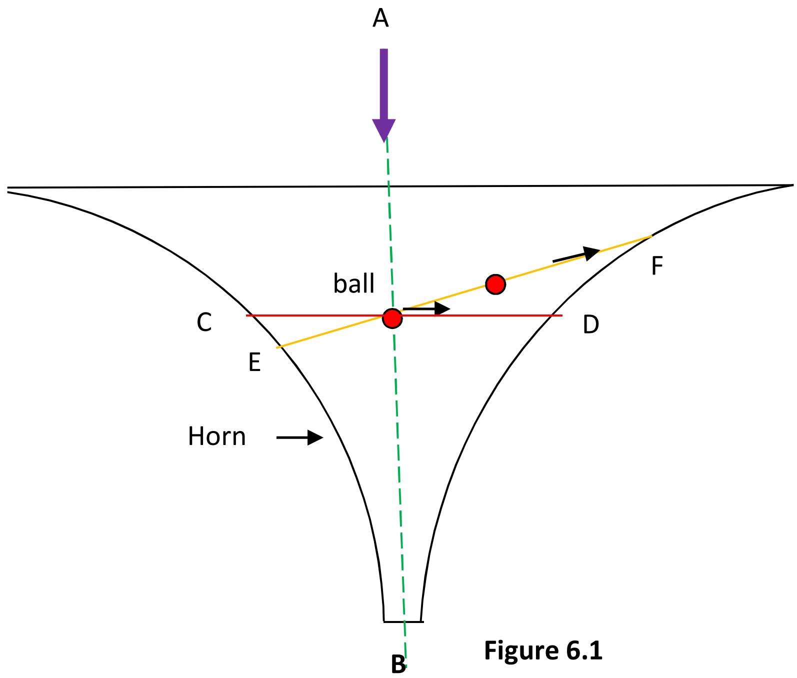

Figure 6.1

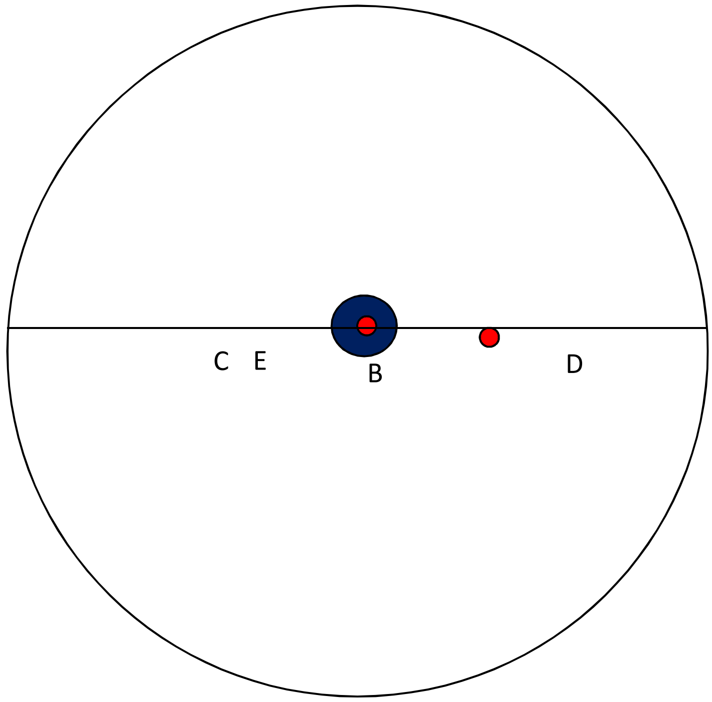

Figure 6.2

Figure 6.1 shows a vertical cross section of a metal horn. A small red ball moves along a line that is horizontal and circular, C, D. However the ball could take the track E, F.

Discuss, using appropriate algebra where possible, the relative energies of the two tracks.
How good a model is this of the solar system?

End of Questions