British Physics Olympiad 2014-2015

BPhO Round 2

Monday 26th January 2015

Instructions

Time: 3 hours (approximately 45 minutes on each question).

Questions: All five questions should be attempted.

Marks: The questions carry similar marks apart from question 2 which has fewer 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 31st January.

Solutions: Answers and calculations are to be written on loose paper or in 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 and pages are numbered.

Clarity: Solutions must be written legibly, in black pen (the papers are photocopied), and working down the page. Scribble will not be marked and this is an important aspect of this exam paper.

Training Dates and the International Physics Olympiad

Following Round 2, in late January, fifteen students eligible to represent the UK at the International Physics Olympiad (IPhO) will be invited to attend the ***Training Camp*** *to be held in the Physics Department at the University of Oxford, (****Monday 30th March –Thursday 2nd April 2015****). 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 or two reserves) will be selected for further training.*

From the early April until late May there will be mentoring by email to cover some topics and more problems.

There will be a weekend ***practical Training Camp in Oxford*** *over the weekend of* ***15th, 16^{th,} 17th May*** *(Friday evening to Sunday afternoon).*

There will be a ***Training Camp at Trinity College, Cambridge*** *(****Sunday 28th June – Friday 3rd July****).*
The IPhO this year will be held in Mumbai, India, from ***Sunday 5 th July to Monday 13th July 2015****.*

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}
Permittivity of free space	ε_o	8.85×10^{-12} m^{-3} kg^{-1} s^{4} A^{2}
Permeability of free space	μ_o	$4\pi \times 10^{-7}$ H m^{-1}
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	6.37×10^{6} m
Radius of the Earth’s orbit	r_E	1.49 x 10^{11} m
Mass of the Sun	M_s	2.0×10^{30} kg
Mass of the Earth	M_E	6.0×10^{24} kg
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}

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

Qu 1.

In this question you are asked to make reasoned estimates, assumptions and explanations. These assumptions and estimations must be clearly stated.

(a)

(i) The planet Venus orbits the Sun. Viewed through weak binoculars it appears to be crescent shaped. Its size and shape appear to change a few days later. Why is this?

(ii) The planet does not appear to change in size and shape to the naked eye. However, its brightness does vary through its orbit. Why?

(iii) It was realised in the 18th century that if two telescopes on different parts of the Earth measured the position of Venus at the same time, the distance from Earth to Venus could be measured and hence the scale of the Solar system (at that time, the radius of the Earth was well known). Why did they need to do this when Venus was in transit across the Sun?

(b) If a long hose is connected to a tap and the end of the hose is partially covered by a thumb, the water squirts out faster. Explain why.

(c) Alpha radiation from a source is observed in a cloud chamber and the tracks are photographed with a digital camera. The density of the track (number of dark pixels/per unit length, $\frac{dN_{\text{dark pixels}}}{dx}$) is plotted against the distance from the source, x. Explain the graph in Figure 1a.

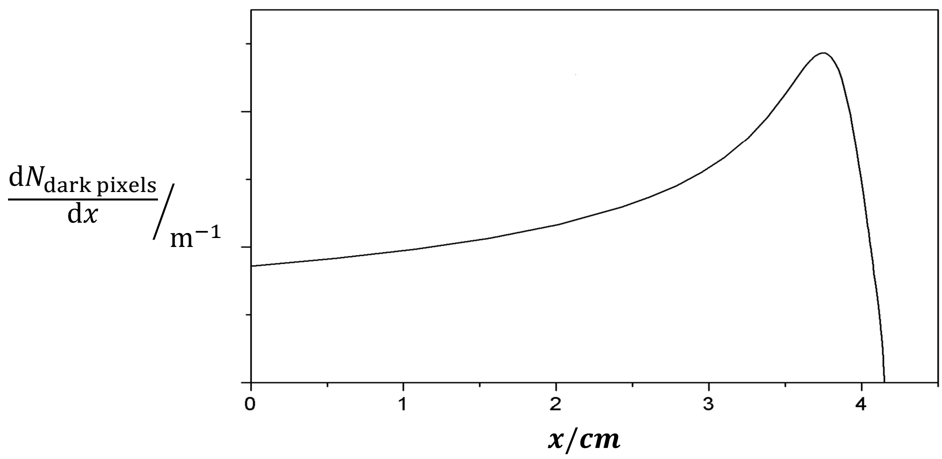

Figure 1a. Range of alpha particles in a gas when emitted by a source.

(d) A beam of electrons is accelerated from rest by a pd of 1kV. The electric field is uniform. The beam current is 1 μA and the diameter of the cross section of the circular beam is 5mm. Calculate:

(i) the maximum velocity of the electrons.
(ii) the velocity of the electrons after they had traversed half the distance in the field.
(iii) the magnetic field a distance of 5mm from the centre of the beam.
(iv) how does the magnetic field vary across the beam?
(v) how does this field effect the electrons?

Qu 2.

Figure 2a shows the cross section of a gully that a cross country skier is skiing into.
Figure 2b shows an aerial view. She wishes to turn left at the gully bottom and continue down the mountain. There is very little wind and air resistance is negligible. However, if she is going at a speed greater than 5 ms^{-1} she will not make the turn and will hit the rubbly snow. (Cross country skis are only attached to the boot at the toe and it is very difficult to execute a small radius turn at speed). If she continues to go up the other side of the gully, shown in Figure 1a, she can then turn very slowly (or stop) in order to turn through 180^{o} and go back. By repeating this procedure up and down the slopes on each side, she will be skiing backwards and forwards until she loses enough speed to turn safely left (or right) down the centre of the gully, as shown in Figure 1b.

The slopes shown are not to scale. Take the maximum slope as 5^{o}. You may assume that the mass of the skier plus equipment is 65 kg. The effective coefficient of friction of the snow is 0.08.

What is the maximum height, h, (Figure 1a) that the she can start from in her final descent so that she is able to make the turn without going up the slope on the other side?

"**Looking North**"

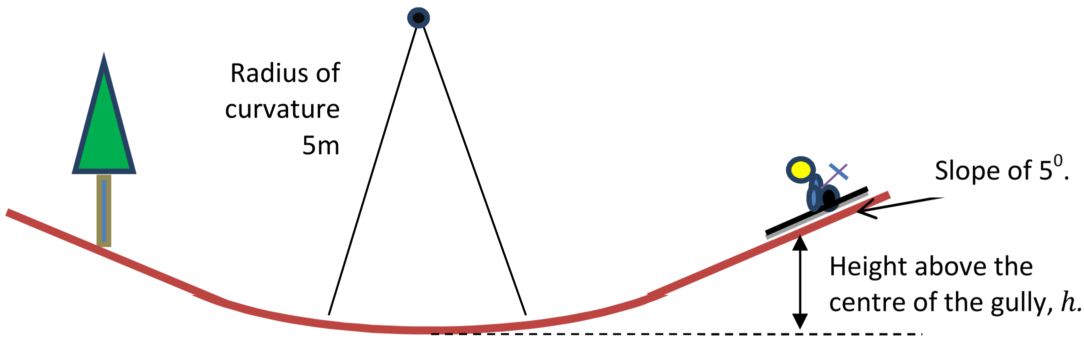

Figure 2a. End view of skier on the slope of a gully, showing the slope in cross section (Note the angle of the slope is greatly exaggerated).

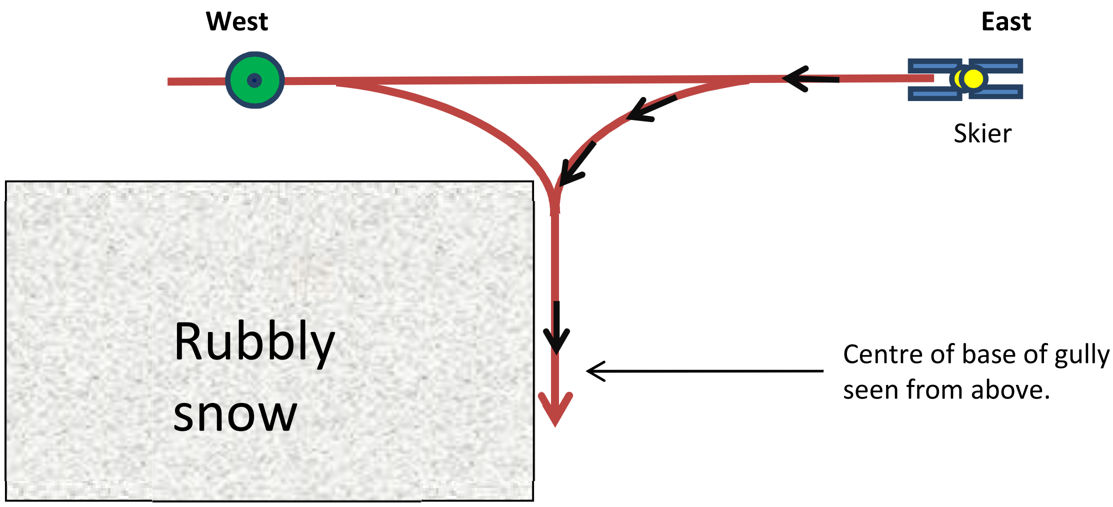

Figure 2b. Aerial view of the skier entering the gully.

Qu 3.

Figure 3a. Observation of a mirror-like effect.

Whilst travelling in the one of the Stans after the end of the 2014 Physics Olympiad in Kazakhstan, the author noticed what appeared to be pools of water on the road and that the headlamps of the approaching vehicle seemed to be reflected in the road. However, this was surprising since the air temperature was about 36 ^{o}C and it had not rained for some time. The refractive index of air at this temperature is about 1.0003.

Briefly account for this phenomenon by means of a description and a diagram. Then consider numerical values to explain the magnitude of the effect.

Marks will be given for the derivation of a formula that gives the geometric path of the light.

The refractive index of the air, $n(z)$, is linearly related to the absolute temperature of the air, which varies linearly with height, z. You may assume that the refractive index has the form

$$n(z) = n(0) + \alpha z$$

with, $\alpha z \ll 1$

(z is not measured from the road level)

Qu 4.

Figure 3a shows simplified design working of a magnetic rifle. The bullet is made of a magnetic material such as iron. The idea is that the trigger switches on the current, this draws the bullet into the solenoid and the bullet proceeds on its way. However trials showed that it did not work. Why do think this was so? Suggest modifications and explain as numerically as you can how your modifications would work.

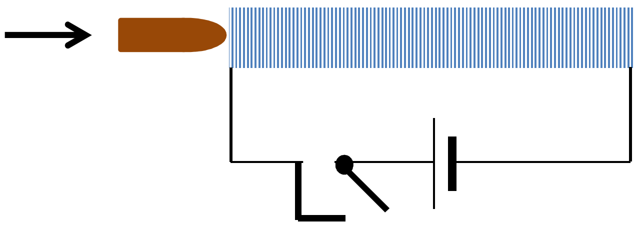

Figure 4a. Magnetic rifle (schematic)

Qu 5.

A lunar eclipse from the year 2000 is shown in Figure 5a below. The composite image is a set of nine separate images taken as a sequence over a period of three to four hours, and has been processed in Adobe Photoshop so that the moon's image is shown relative to the Earth's shadow. It shows various stages of the total lunar eclipse of Jan 20-21 2000, observed from Maryland in the United States. The three images of the moon at the centre of the composite are some 10 000 times fainter than the surrounding images of the moon, and have been enhanced in this composite image. The reddening of the image is due to the scattering effect of light in the earth's atmosphere.
The angular diameter of the moon subtended at the earth is about 0.52^o, whilst the angle subtended by the sun at the earth is on average about 0.53^o.

Figure 5a. Composite image of a total lunar eclipse of January 21, 2000, oberved from Maryland USA over a period of three to four hours.

TLE2000umbra2w
http://www.mreclipse.com/LEphoto/TLE2000Jan/TLE2000Jan-1B.html
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The diameter of the earth is 6370 km and the sun is much larger, but at a very great distance away compared to the Earth-Moon distance. Using the information provided, estimate the distance from the Earth to the Moon.
Use sketch diagrams to show your method.

End of Questions