AS COMPETITION PAPER 2011
SOLUTIONS

Total Mark/50

2011 AS Competition Paper

Mark Scheme and Notes for Teachers

Thank you for entering the 2011 British Physics Olympiad AS Competition. Please note the following information:

Before the test

It is intended that the paper should be taken on Friday 18th March. However, if this is not possible, any date during the period **14th –25th March** will be acceptable.

During the test

The paper lasts one hour.

Candidates may use any calculator and should write their answers directly on the exam script.

After the test

Teachers should mark their students' scripts. The mark scheme begins overleaf. Certificates are awarded in the following manner

Award	Gold	Silver	Bronze	Participation
Mark Range	50 – 38	37 – 26	25 – 14	13 – 0

Free certificates can be claimed for participating students. To order certificates please go to http://www.physics.ox.ac.uk/olympiad/Enter.html

The scripts of any Gold Award Winners (those scoring 38 or above) should be sent to the address below for consideration in the national competition. Please ensure the student's name and school is written clearly. Scripts must arrive by Monday **28th March** to be considered for a national prize.

BPhO Office, Clarendon Laboratory, Parks Road, Oxford, OX1 3PU

Five outstanding Gold Medalists, together with their teachers will be invited to the BPhO Presentation Ceremony at The Royal Society in London on Thursday 28th April 2011.

If you have any further questions please contact us on schools.liaison@physics.ox.ac.uk

Marking

The mark scheme is prescriptive, but markers must make some allowances for alternative answers.

A value quoted at the end of a section must have the units included.

Candidates lose a mark the first time that they fail to include a unit, but not on subsequent occasions except where it is a specific part of the question.

Significant figures are related to the number of figures given in the question. A single mark is lost the first time that there is a gross inconsistency (more than 2 sf out) in the final answer to a section.

Ecf: this is allowed in numerical sections provided that unreasonable answers are not being obtained. Ecf can not be carried through for more than one section after the first mistake (e.g. a mistake in section (d) can be carried through into section (e) but not then used in section (f)).

Note: 'owtte' – or words to that effect

Section A: Multiple Choice

1. **B**
2. **D**
3. **D**
4. **A**
5. **C**

6. **B**
7. **B**
8. **D**
9. **B**
10. **A**

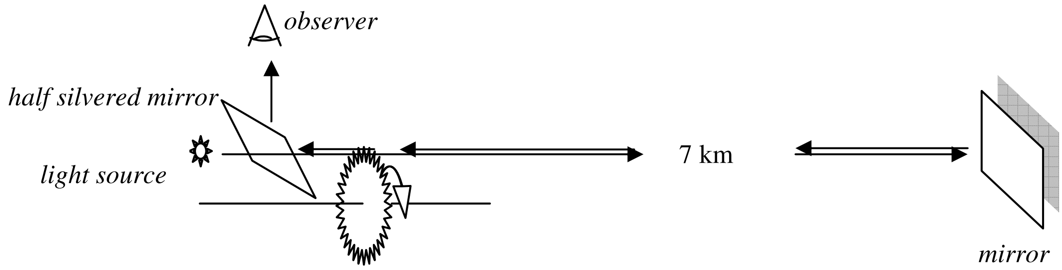
There is 1 mark for each correct answer.

Maximum 10 marks

Section B: Written Answers

Question 11.

In one of the original experiments to measure the speed of light, carried out by Fizeau in 1849, a beam of light was sent to a distant mirror 7 km away and reflected back, passing through the teeth of a rapidly rotating cogwheel. It is best to detect when the light is obscured by a tooth on its return path and a reduction in intensity is observed. A simplified diagram of the setup is shown below. The toothed cog has 720 teeth and rotates several hundred times per second.



a) At a rate of rotation of 283rps (rotations per second) extinction is observed. Speeding up the cog, extinction is next observed at 313 rps. Explain why the light is extinguished at a particular rate of rotation.

the light has to travel there and back (meanwhile) ✓

(a whole number of gaps &) a tooth has moved into the path of light ✓ [2]

owtte

b) Explain why there are two (or more) rates at which extinction is observed.

several additional pairs of teeth and gaps can pass by whilst the light is on its journey ✓

owtte [1]

c) If $n + ½$ teeth cross the beam at 283 rps, state how many teeth must cross the beam at 313 rps? Calculate the number of teeth that cross the beam per second at each of the two speeds, the difference in the number of teeth crossing per second, and thus the time interval for one extra tooth to cross. (This is the travel time of the light beam)

$n + ½ + 1$ teeth ✓

313 x 720 = 225,360 tps & 283 x 720 = 203,760 tps so 21,600 extra teeth per sec pass ✓

time interval is 1/21,600 = 4.63×10^{-5} s ✓ [3]

d) Calculate the speed of light from these measurements.

c = 14,000 / 4.63×10^{-5}

= $3.0(24) \times 10^{8}$ ms^{-1} ✓ [1]

/7

Question 12.

A solid sphere of mass *m* rolls down a slope. The sphere gains kinetic energy in two forms: *rotational kinetic energy* and *translational kinetic energy* in which the centre of mass moves along at speed *v*. For the solid sphere, a fixed fraction, $\frac{2}{7}$, of the gravitational potential energy lost as it rolls down the slope appears as *rotational kinetic energy*.
If the sphere now rolls along a flat surface at a speed of 4.0 ms^{-1} and then encounters a rising slope at 30^o to the horizontal, we can calculate how far up the slope the sphere will rise. We can take the mass of the sphere as 1 kg.

a) Calculate the translational KE of the sphere and hence the total energy of the rolling sphere.

$\frac{1}{2} mv^2 = 8$ J ✓

this is 5/7 of the total energy ✓

total energy = 7/5 x 8 = 11.2 J ✓ [3]

b) Describe the energy changes that take place as the sphere rolls up the slope.

Translational & rotational ✓ KE lost / converted ✓

.gravitational PE gained ✓ [3]

c) What is the vertical height reached up the slope?

$mgh = 11.2$ J ✓

$h = 11.2/9.8 = 1.14$ m ✓

[2]

d) How far up along the slope does this take the sphere?

sin 30^o = height/slope length ✓

slope length = height/0.5 = 2.3 m ✓ [2]

/10

Question 13.

The resistance of a wire is proportional to its length and inversely proportional to its cross sectional area. The resistance of a wire of length ℓ and cross sectional area A is given by $R = \frac{\rho\ell}{A}$ where ρ is a constant which depends upon the material of the wire. Some metals are ductile, which means that they can be drawn into long thin wires. In doing so, the volume V remains constant whilst the length increases and the cross sectional area of the wire decreases.

A wire of length 32 m has a resistance of 2.7 Ω. We wish to calculate the resistance of a wire formed from the same volume of metal, but which has a length of 120 m instead.

a) Write down the relation between V, A and ℓ. Obtain an expression to show how R depends upon the length ℓ of the wire and its volume V.

$A = \frac{V}{\ell}$ or arrangement ✓

$R = \frac{\rho\ell^2}{V}$ ✓ [2]

b) Rewrite the equation with the constants ρ and V on one side and the variables we are changing, R and ℓ, on the other.

$\frac{V}{\rho} = \frac{\ell^2}{R}$ or $\frac{\rho}{V} = \frac{R}{\ell^2}$ ✓

[1]

c) Calculate the resistance of the longer wire.

$\frac{R_{old}}{\ell^2_{old}} = \frac{R_{new}}{\ell^2_{new}}$ ✓

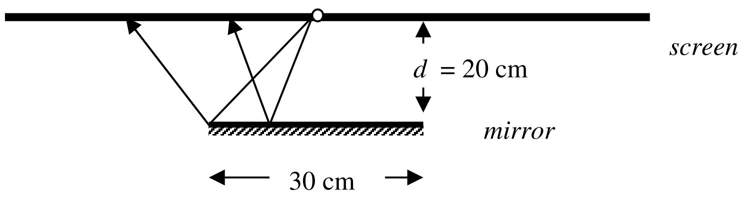
$\frac{2.7}{32^2} = \frac{R_{new}}{120^2}$ ✓

$R_{new} = 38\ \Omega$ ✓ full marks for correct answer [3]

/6

Question 14.

A point source of light is embedded in a large screen. A circular mirror of diameter 30 cm is placed 20 cm in front of the screen, parallel to it and with the centre of the mirror lying along the normal to the screen which passes through the point light source.



a) Sketch the path of the light rays on the diagram above.

two reasonable rays shown ✓ [2]
angle of incidence ≈ angle of reflection (by eye) ✓

b) Calculate the area of illumination on the screen.

by calculation of angle or by observation that diameter of

illuminated circle is twice that of the mirror ✓

area = 4 x πR^2_{mirror} = 0.28 m^2 ✓ [2]

c) If the distance from the screen to the mirror is now given by *d*, how does the area of illumination depend upon separation *d*?

area of illumination independent of *d* ✓

as $\angle i = \angle r$ owtte ✓

[2]

d) Describe qualitatively how the intensity of light reaching the screen depends upon the separation *d* for smaller and larger values of *d*.

the intensity is reduced for larger values of *d* ✓

at large *d* the intensity is nearly uniform ✓

at small *d* the intensity is much greater at the centre of the circle of light ✓

[3]

/9

Question 15.

In an experiment carried out in 1959 by Pound and Rebka at Harvard University, Einstein's General theory of Relativity was tested by measuring the change in frequency of a photon of the electromagnetic spectrum when it went downwards in the gravitational field of the earth. A 14 keV γ-ray is emitted downwards by a radioactive isotope of iron (Fe-57), and as it falls down in the gravitational field of the earth its energy and hence its frequency increases. A relatively simple classical calculation turns out to give the right result for the frequency change.

a) To determine the frequency of the initial 14 keV photon, convert the energy into joules and, using the relation between energy and frequency of photon $E = hf$, calculate the frequency.

$14 \times 10^{3} \times 1.6 \times 10^{-19} = 2.24 \times 10^{-15}$ J ✓

$f = 2.24 \times 10^{-15} / 6.6 \times 10^{-34} = 3.4 \times 10^{18}$ Hz ✓ [2]

b) If we associate a fictitious mass m to the gamma ray photon, given by $m = \frac{E}{c^2}$ then the energy change of the photon as it falls in the earth's field through a distance Δd is given by the familiar potential energy change in a gravitational field, $\Delta E = mg\Delta d$. Express this as a change of frequency of the gamma ray photon Δf.

$\Delta f = \frac{\Delta E}{h} = \frac{mg\Delta d}{h}$ ✓ for one aspect of the result

$\Delta f = \frac{hf}{c^2}\frac{g\Delta d}{h} = \frac{fg\Delta d}{c^2}$ ✓ up to 3 marks [3]

c) If the distance the photon falls is 22.5 m, calculate both the change in frequency and the fractional change in frequency $\frac{\Delta f}{f}$ of the gamma ray photon.

$\Delta f = 3.4 \times 10^{18} \times 9.8 \times 22.5 / 9 \times 10^{16} = 8.3$ kHz ✓ ecf

$\Delta f / f = 2.5 \times 10^{-15}$ ✓ ecf

[2]

d) This small frequency change is detected by using the Doppler Effect in which a moving source emits a wave whose frequency is modified by its motion. The fractional change of frequency emitted is given by the ratio v/c where v is the speed of the source required. Calculate v.

$\Delta f / f = 2.5 \times 10^{-15} = v/c$ so $v = 2.5 \times 10^{-15} \times 3 \times 10^{8} = 7.4 \times 10^{-7}$ ms^{-1} ✓ ecf [1]

speed of light, $c = 3.0 \times 10^{8}$ ms^{-1}
Planck's constant, $h = 6.6 \times 10^{-34}$ Js
$e = 1.6 \times 10^{-19}$ C

/8