AS CHALLENGE PAPER 2012
SOLUTIONS

BPhO
British Physics Olympiad

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 cannot 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)).

owtte: “or words to that effect” – is the key physics idea present and used?

Section A: Multiple Choice

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

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

There is 1 mark for each correct answer.

Maximum 10 marks

Multiple Choice Solutions

Qu. 1 The laws of physics are the same in different inertial (constant velocity) reference frames. Alternatively, viewed from outside the lift, when the stone is released it is observed to be rising at speed *v,* i.e. that of the lift, whilst the floor is rising at this speed. So the time taken for it to reach the floor is the same.

Qu. 2 The energy for cooking the potatoes is $P \times t$ and since P is constant the energy depends only on t. A 100 g potato would take 3 mins so 1200 g will take twelve times longer, i.e. 36 mins.

Qu. 3 The downward force on the mass is mg and an upward force that was different to mg would produce a resultant force and hence an acceleration, according to Newton's 1st Law of Motion. So as there is no acceleration, the upward force and downward force must be equal (and opposite).

Qu. 4 Mirror A is reflected in mirror B and vv. These reflections are themselves reflected in B and A, so that mirrors can be seen every 15^o through the whole 360^o of a "circle". These images of the mirrors will each have an image of O between them. So an image is seen every 15^o, giving 360/15 = 24 images (including the original object).

Qu. 5 Energy = V x I x t. Current might be 0.3 A for a bulb and lasting for 8 hours until the battery goes flat. So energy = 1.5 x 0.3 x 8 x 3600 = 12,960 J Lots of variation allowed on I and t, but not enough to obtain as much as 3×10^5 J

Qu. 6 Jack throws his penny up and it decelerated by g, whilst on the way down it falls back to the window level with the same acceleration of g and taking the same time. So it passes the window on the way down with the same 4 m/s that it started with on the way up. So it is indistinguishable from Jill's penny.

Qu. 7 If we take moments about the pivot, with the extended masses being treated as point masses at their centres, then anticlockwise moment is 3m x b and the clockwise moment is m x (5-b) + m x (10 – b) where b is the number of units from the left hand end (b=5 is the centre)

i.e. $3b = (5-b) + (10-b) \Rightarrow b = 3$

Qu. 8 This is an example of an unstable equilibrium; if the balloon is floating a little below the surface then if it sinks lower, the air is compressed and it will sink lower still, which causes further compression of the air, etc.

Qu. 9 If both elements are used at the same time then the time taken to heat the urn will be shorter than either t_1 or t_2. The only result which satisfies this is D.

Calculation gives $E = (P_1 + P_2)\,t$ where E is the energy need to heat the urn in time t with powers P_1 and P_2 supplied

For the individual heaters,

$P_1 = E/t_1$ and $P_2 = E/t_2$

So $E = (E/t_1 + E/t_2)\,t$

$1/t = 1/t_1 + 1/t_2$

$$t = \frac{t_1 t_2}{t_1 + t_2}$$

Qu. 10 Number of molecules ionized is $4.0 \times 10^6/34$

Distance between molecules is $7 \text{ cm} \times 34 / 4.0 \times 10^6 = 5.95 \times 10^{-5}$ cm

$= 5.95 \times 10^{-7}$ m

Section B: Written Answers

Question 11.

The weights shown in figure 2 below are balanced on strings and pulleys of negligible mass and friction. The masses m_A and m_B are not the same.

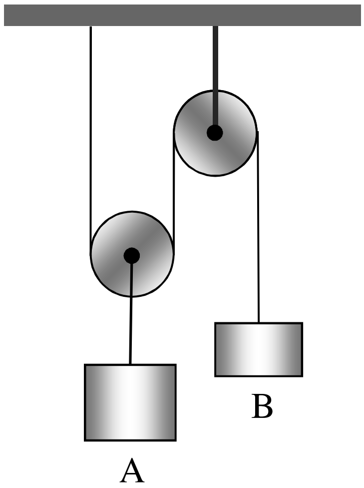

Figure 2.

a) If mass **A** is pulled down by a distance h, how far does mass **B** move?

$2h$ (upwards) ✓

[1]

b) In terms of masses m_A and m_B, what would be the changes of gravitational potential energy (gpe) of each mass and what would be the change in gpe of the whole system?

A (loses) $m_A gh$

B (gains) $m_B g\ 2h$ ✓ both needed

Change in gpe = $(2m_B - m_A)gh$ ✓ [2]

c) When **A** is pulled down and then released, the masses remain stationary in their new positions. How has the gravitational potential energy of the system changed from the start?

Zero change ✓

[1]

d) What is the ratio of the masses $\frac{m_A}{m_B}$? Give a reason for your answer.

Since no change of PE, $(2m_B - m_A) = 0$ reason ✓

$2m_B = m_A$ ✓ [2]

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Question 12.

A student decides to calibrate a thermistor in order to measure variations in the temperature of the room. He connects a small bead sized thermistor across the terminals of a 5 V power supply and in series with a 1 A ammeter. The resistance of the thermistor is 120 Ω at room temperature.

a) Instead of showing small variations in room temperature, the thermistor is likely to go up in smoke. Explain why.

Current flows and power is converted/heat energy produced (in the thermistor) ✓

Calculation $P = V^2/R = 25/120 = 0.2$ W ✓

This causes the temperature of the thermistor to rise and its resistance to fall ✓

Increased current flow so more heat energy produced ✓

Cycle continues until thermistor overheats/is destroyed ✓

Max (4) [4]

In the light of his experience, he decides to redesign his simple circuit as is shown in figure 3 below. He has a few values of resistor R to choose from; 5 kΩ, 500 Ω, 50 Ω.

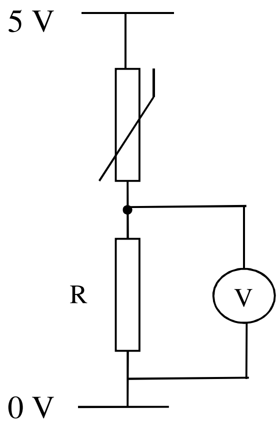

Figure 3.

b) State which value of *R* would give the biggest variation of V with temperature. Explain your choice.

50 Ω as the variation of R_{th} would be relative to (50 + 120) Ω, the ✓

(The change in potential is the change in R_{th} relative to) smallest total resistance owtte

✓ [2]

c) State which value of *R* would be most likely to cause the same problem as in (a). Again, explain your choice.

50 Ω is the smallest resistance and might be too little to prevent the

"thermal runaway" described in part (a) owtte ✓ [1]

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Question 13.

Two pendulums shown in figure 4 below have equal masses at the end of light straight rods, but one pendulum (of length 2ℓ) is twice the length of the other (of length ℓ).

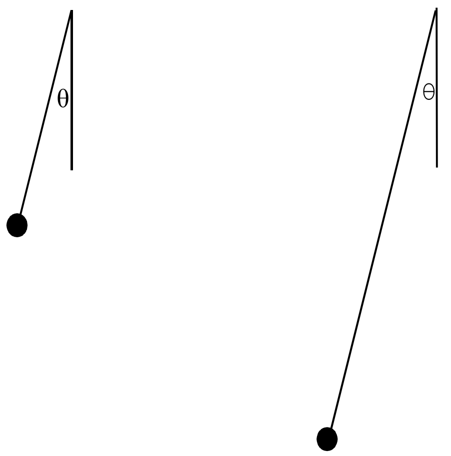


Figure 4.

a) When they are swung through the same initial angle θ and released, which of them has the greater energy in its swing? Give a reason for your answer.

The longer pendulum ✓

because the mass is **raised** to a greater height Or the **change** in height is greater ✓ [2]

b) Each pendulum is released from a horizontal position where the mass at the end is level with the support. The speed at the bottom of the swing for the long pendulum is v_L and the speed at the bottom of the swing for the short pendulum is v_S. By considering the potential and kinetic energy of each pendulum, what is the ratio $\frac{v_L}{v_S}$?

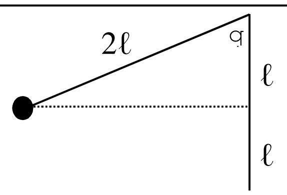
Gpe to KE statement **or** the equations $mg\ell = \frac{1}{2} m v_S^2$ and $mg2\ell = \frac{1}{2} m v_L^2$ ✓

So $\frac{v_L}{v_S} = \sqrt{2}$ ✓

[2]

c) If the short pendulum is released from a horizontal position again, and achieves speed v_S at the bottom of the swing, from what angle θ should the longer pendulum be released so that it reaches the same speed of v_S at the bottom of its swing?

Needs the same starting height ℓ ✓



cos q = $\ell/2\ell$ = ½ so q = 60° ✓ [2]

/6

Question 14.

The volume of a car tyre is 20 litres when correctly inflated. The tyre is found to be flat so that the rim of the wheel is sitting on the ground. It still has 16 litres of air in the tyre at atmospheric pressure. An electrically operated air pump is available. This works using a tiny piston in a cylinder which oscillates very fast and can pump air from the atmosphere through the pump at the rate of 4 litres/minute. We will assume that the temperature remains constant.

a) The extra volume of 4 litres would be filled in 1 minute at 4 litres/min. Explain why it takes very much longer than 1 minute to correctly inflate the car tyre.

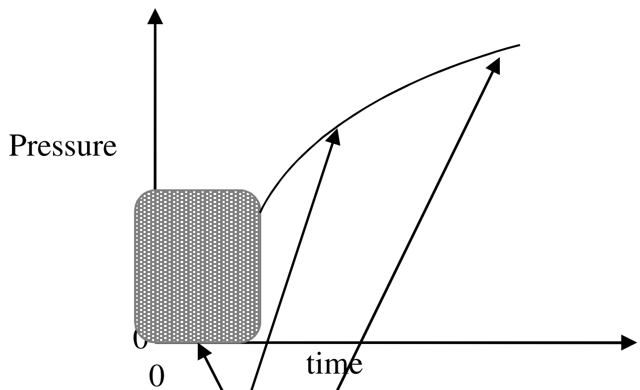
As the air is pumped in, the pressure increases ✓

So a volume of air from the atmosphere is compressed to a smaller volume in the tyre ✓

owtte

[2]

b) Sketch a graph showing how the air pressure in the tyre might increase with time after the first few minutes.



[2]

Either graph as starting pressure can be 1 atmosphere or zero

- Not horizontal at the top end ✓
- Concave downwards ✓
- Ignore the first few minutes

c) When the tyre is filled with air at one atmosphere of pressure, it will not lift the rim off the ground. An excess pressure is required for that purpose. When inflated, each car tyre has about 130 cm^2 of area in contact with the ground. If the car has a mass of 1,200 kg, what is this excess pressure in a car tyre needed to lift the weight of the car? Express this in terms of atmospheric pressure.

Atmospheric pressure is 1.0 x 10^5 Pa.

$P = \frac{1200 \times 9.8}{4 \times 130}$ = 22.6 N/cm^2 ✓ 4 wheels ✓

= 226,000 Pa

= 2.26 Atmospheres ✓ (allow g = 10 N/kg)

(= 2.3 At) [3]

d) Boyle's Law for a gas states that P x V = constant, and this can be used to relate the volume and pressure of the air inside and outside the tyre when it is correctly inflated. What is the volume of air taken from the atmosphere which provides the excess pressure in the tyre?

4 litres at atmospheric pressure to fill the tyre up to 20 litres to be fully inflated

then extra air to provide the extra pressure ✓

3.26 x 20 litres = 1 x V_2 Boyles Law applied (letters or values) ✓

V_2 = 65.2 litres = 65 litres ✓ use of 16 litres loses one mark [3]

e) How long would it take the pump to correctly inflate the tyre when it is flat and sitting on the rim with only 16 litres of air in it?

1 minute ✓

+ 65.2/4 minutes allow ecf ✓

= 17 minutes [2]

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Question 15.

In a particle physics experiment, light from a particle detector is to be collected and concentrated by reflecting it between a pair of plane mirrors with angle 2α between them, as shown in figure 5 below. A faint parallel beam of light consisting of rays parallel to the central axis is to be narrowed down by reflection off the mirrors, as shown by the single ray illustrated, for which angle a = α.

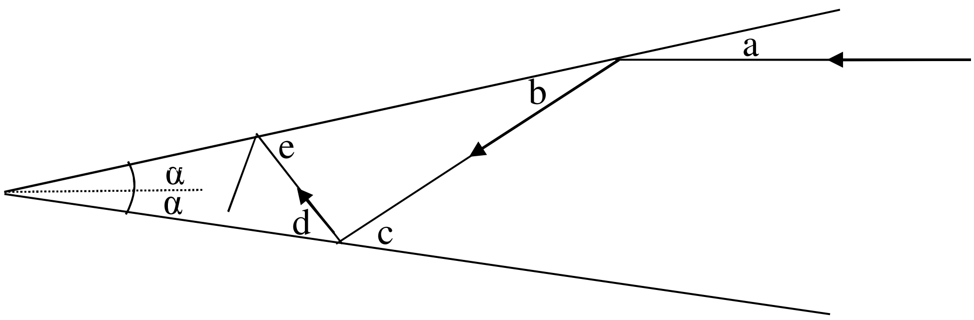

Figure 5.

a) Determine angles b, c, d, and e in terms of angle α.

(a is α) b is α ✓

c is 3α d is 3α ✓

e is 5α ✓

[3]

b) Explain what happens after several reflections of the light down the mirror funnel.

The angle of incidence becomes greater than 90^o ✓

The ray reflects back out of the opening (ignore parallel) ✓ [2]

c) If angle α is 10^o what is the total number of reflections between the mirrors that will be made by a beam, of light entering parallel to the axis of symmetry as shown?

Reflections off the sides: a = 10^o , c = 30^o, e = 50^o, then 70^o then 90^o

Then ray reflects back,(following the same path for this particular angle)

Which means 4 + 1 + 4 = 9 reflections ✓ [1]

d) If the mirrors are replaced by an internally silvered circular cone whose cross-section is the same as that shown above, why will this not make any difference to the calculations given above for the plane angled mirrors with a beam of light parallel to the axis?

(No) because the incident ray, normal, and reflected ray all lie

in a plane containing the axis of symmetry owtte ✓

[1]

e) An ear trumpet is not very common now, but it was used to collect sound and focus it in to the ear. It was a cone about 0.5 metres long with an angle 2α of about 30^o. Sound might have a frequency of 400 Hz and the speed of sound is 330 m/s. Why is the model above that we have used for light not valid for an ear trumpet used to collect sound?

$\lambda = v/f = 330/400 = 0.8$ m ✓

wavelength is similar to the size of the trumpet aperture and so

diffraction ✓

will be important [2]

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