BPhO
British Physics Olympiad

AS CHALLENGE PAPER 2016 SOLUTIONS

Marking

The mark scheme is prescriptive, but markers must make some allowances for alternative answers. It is not possible to provide notes of alternative solutions which students devise since there is no opportunity to mark a selection of students' work before final publication. Hence alternative valid physics should be given full credit. If in doubt, email the BPhO office.

A positive view should be taken for awarding marks where good physics ideas are rewarded.

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.

The paper is not a test of significant figures. 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 question. Almost all the answers can be given correctly to 2 sf.

ecf: this is allowed in numerical sections provided that unreasonable answers are not being obtained.

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

Section A: Multiple Choice

Question 1. **C**
Question 2. **D**
Question 3. **D**
Question 4. **C**
Question 5. **C**
Question 6. **A**

There is 1 mark for each correct answer.

Maximum 6 marks

Multiple Choice Solutions

Qu. 1 Energy change = work done = force x displacement = $\mathrm{MLT^{-2}} \times \mathrm{L} = \mathrm{M}\frac{\mathrm{L^2}}{\mathrm{T^2}}$

Qu. 2 Since the liquid is incompressible, what goes in of volume each second must go through the smaller pipe. So the flow rate remains at $6\ \mathrm{m^3 s^{-1}}$

Qu. 3 However, the fluid must speed up in order to get through the small tube. The cross sectional area is $\frac{1}{9}$ th of the larger tube area, so the speed must be 9 times greater.

Qu. 4 (**5 & 6**) Resolving the forces on the join in the string vertically

$$T\cos 45° = mg$$

And horizontally

$$T\sin 45° = F$$

And dividing

$$\tan 45° = \frac{F}{mg}$$

And with $\tan 45° = 1$ then $F = mg$

Section B: Written Answers

Question 7.

a) Distance (or displacement) = area under graph ✓
Area = (rectangle) $ut +$ ✓
(triangle) ½ base x height or $\frac{1}{2} \times t \times a\ [= (v-u)/t]t = \frac{1}{2}at^2$ ✓
$a \times t$ is the height, the gradient times the base.
Must be clear how the terms are obtained.

[3]

b) This is a subtlety of constant acceleration. The falling object increases in speed by the same amount as the rising object loses speed, as the travel time is the same and the acceleration, g, is the same (acceleration is change of speed ÷ time). So the height h is covered in time t at speed v. Hence $h = vt$. ✓✓✓
The argument must be quite clear and without obfuscation as the answer is given.

OR by calculation: [**convention** $h\ \uparrow, y\ \downarrow, g\ \downarrow, v\ \uparrow$, so $(h-y)\uparrow$, etc.]
v_t, v_b are the speeds of the top/bottom particles when they meet

$v_t = gt$ and $v_b = v - gt$ ✓

So $v_t + v_b = v$ ✓

$h = \frac{1}{2}(v - v_b)t + \frac{1}{2}v_t t$ ✓

Hence $h = vt$

Alternatively

A starting point – rising particle: $h - y = vt - \frac{1}{2}gt^2$ ✓

Reasoning – and with $y = \frac{1}{2}gt^2$ ✓

$h - y = vt - y$ ✓

$h = vt$ (no mark for the result)

[3]

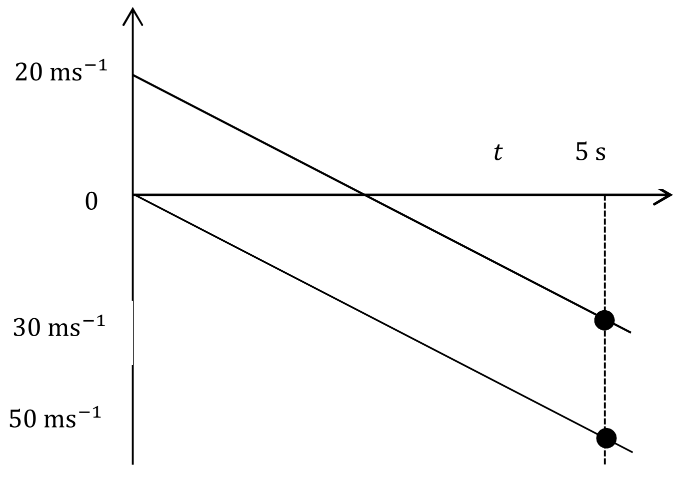
c) Falling object $y = \frac{1}{2}gt^2$ ✓

And $h = vt$

Therefore $y = \frac{1}{2}g\frac{h^2}{v^2}$ ✓

[2]

d)



Parallel lines with one crossing t axis and one through origin ✓ (may be inverted)

Two points at the same t ($5\ s$) and below the time axis. ✓

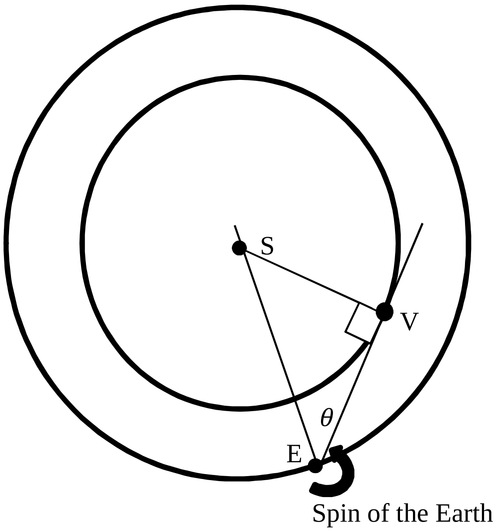
$v_t = -gt = -50\ \text{ms}^{-1}$

$v_b = v - gt = -30\ \text{ms}^{-1}$ ✓

[3]
Total 11

Question 8.

Diagram



Informative diagram to illustrate the angle between Sun and Venus ✓

$$\sin\theta = \frac{0.72}{1.0}$$ ✓

or $\theta = 46°$

idea that planets remain in position whilst Earth spins in a few hours ✓

$$\text{time before sunrise} = \frac{46°}{360°} \times 24 = 3 \text{ hours } 4 \text{ minutes} \approx 3 \text{ hours}$$ ✓

[4]

Total 4

Question 9.

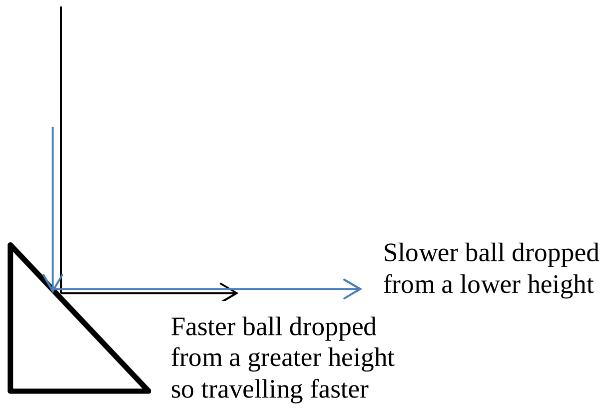


Diagram ✓

The balls fall with constant acceleration from two different heights. ✓
When they bounce off the 45° slope, their speeds then remain constant ✓
As there is no component of gravity/no force on them
The elastic collisions maintain their speeds that they gained in the fall ✓
Travelling at different constant speeds, the faster ball (dropped from the greater height) will collide with the slower ball. ✓

[5]

Note that this calculation is not required.

The calculation of the horizontal distance s travelled is N.B.(h, h') are the starting heights

vertically $h = \frac{1}{2} g t_V^2$ and horizontally $s = v t_H$ (constant speed x time)

So that $t_H + t_V = t_{total} = \sqrt{\frac{2h}{g}} + \frac{s}{v}$

Similarly $t_{total} = \sqrt{\frac{2h\prime}{g}} + \frac{s}{v\prime}$

And with $v^2 = 2gh$

$v'^2 = 2gh'$

$$\sqrt{\frac{2h}{g}} + \frac{s}{\sqrt{2gh}} = \sqrt{\frac{2h'}{g}} + \frac{s}{\sqrt{2gh'}}$$

Multiply through by $\sqrt{2g}$ to give $\frac{2h'+s}{\sqrt{h\prime}} = \frac{2h+s}{\sqrt{h}}$

Rearranging gives $s = 2\sqrt{hh'}$

Total 5

Question 10.

a) Since the resistivity is much less than copper, the cube will need to be much larger.

$1.68 \times 10^{-8} = 0.53 \frac{l}{l^2}$ ✓

$l = 3.2 \times 10^7$ m ✓

[2]

b) A semiconductor has many fewer free electrons (by a factor of 10^8 or more) ✓

[1]

c) $I = \frac{\mathcal{E}}{R + R_c}$ ✓

[1]

d) $N = \frac{L}{2r}$ ✓

$l = N 2\pi a = \frac{L}{2r} 2\pi a = L\pi \frac{a}{r}$ ✓

[2]

e) $R_c = \frac{\rho l}{\pi r^2} = \frac{\rho}{\pi r^2} L\pi \frac{a}{r} = \frac{\rho a}{r^3} L$ (use of $R = \frac{\rho l}{A}$✓) ✓

[2]

f) $B = \mu_o \frac{N}{L} I = \mu_o \frac{1}{2r} \frac{\mathcal{E}}{\left(R + \frac{\rho a}{r^3} L\right)}$ three terms ✓

Correct denominator term ✓

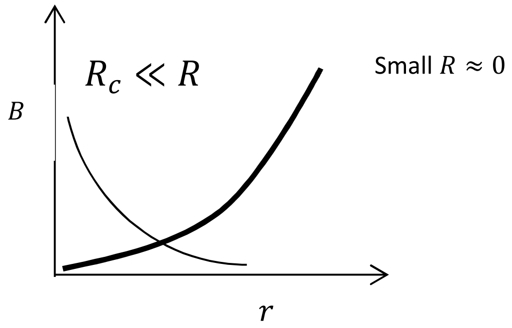
[2]

g) For $R \approx 0$ $B = \mu_o \frac{1}{2r} \frac{\mathcal{E} r^3}{\rho a L} = \mu_o \frac{\mathcal{E} r^2}{2\rho a L}$ ✓ **[1]**

h) $R_c \ll R \qquad B = \mu_o \frac{\varepsilon}{2rR}$ ✓

i.e. Independent of the geometry of the coil, but does depend on r **[1]**

i)



graphs ✓

Labels to state which is which ✓

[2]

Total 14

Question 11.

Rounding errors are not penalized

Any order is allowed

Data really to 2 sf but avoiding multiple rounding errors

5 W electrical → 62.5 W thermal ✓

Thermal power with 5.5 MeV per decay and 1.6 MeV = 1.6×10^{-13} J

….is 8.8×10^{-13} J per decay ✓

Results in 7.1×10^{13} decays per second ✓

Half life in seconds used in calculation 2.8×10^{9} seconds ✓

Number of decaying atoms (molecules) $N_o = \frac{A_o t_{\text{hl}}}{0.693}$ = 2.8×10^{23} ✓

No of moles calculated $\frac{N_o}{N_A} = 0.47$ moles ✓

Calculation of mass of PuO_2: 238 + 16 + 16 = 270 g/mole ✓

So 127 g of pure PuO_2 ✓

80% factor as not all Pu is radioactive (wrong isotope) 159 g ✓

Density calculation $15.9 \text{ cm}^3 \approx 16 \text{ cm}^3$ ✓

Individual intermediate values may not be calculated, but if the subsequent value is obtained then credit should be given.

ECF allowed. If the right calculation given with the wrong numbers then credit given unless numbers are silly (e.g. 1000 atoms used, say)

[10]

Total 10

END OF SOLUTIONS