AS CHALLENGE PAPER 2015
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. **D**
Question 2. **C**
Question 3. **A**
Question 4. **D**
Question 5. **C**

There is 1 mark for each correct answer.

Maximum 5 marks

Multiple Choice Solutions

Qu. 1 power/volume = $3.8 \times 10^{26} \big/ \frac{4}{3}\pi(7.0 \times 10^{8})^{3} = 0.26$ W m^{-3}

Qu. 2 ½ mv^2 is ½ x 6.0 x 10^{24} x 30 000^2 = 2.7 x 10^{33} J

Qu. 3 $c = f\lambda$. So $\lambda = \frac{c}{f} = \frac{3\times10^{8}}{9.2\times10^{9}} = 0.033$ m $= 3.3$ cm

Qu. 4 10^{-7} eV = 10^{-7} x 1.6 x 10^{-19} C x 1 J/C = 1.6 x 10^{-26} J
So 1.6 x 10^{-26} J = $mgh = 1.67 \times 10^{-27} \times 9.81 \times h$.
Hence $h = 0.98$ m.

Qu. 5 The shallower slope has a smaller component of g along it ($g \sin\theta$) and so it will have a smaller acceleration than on a steep slope and, as it is also a greater length, it will take longer for the particle to slide down.
The displacement changes are different, as the particle starts off at the same point at the top but ends up at different final points.
The speed at the bottom is the same: an approach is through the equations of motion, but since there is no friction, an energy approach is relatively straightforward.
$mgh = ½\, mv^2$ $\Rightarrow v = \sqrt{2gh}$ where h is just the vertical height.

Section B: Written Answers

Question 6.

a) Average power $= \frac{mgh}{t} = \frac{2\times9.81\times20}{2.02}$ mark for an explicit formula or the numbers shown, but not for implied calculation ✓

$s = \frac{1}{2}at^2$ so $t = 2.02$ s

$P_{av} = 194$ W or 190 W ✓

(*both marks if the correct answer)*

b) The instantaneous power is Fv

$F = mg$ and $v^2 = 2as$

$F = 19.6$ N

$v = 19.8$ m s^{-1} (mark for one of these values)✓

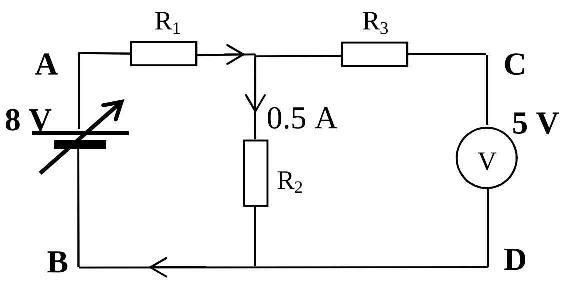
$P_{inst} = 388$ W or 390 W ✓

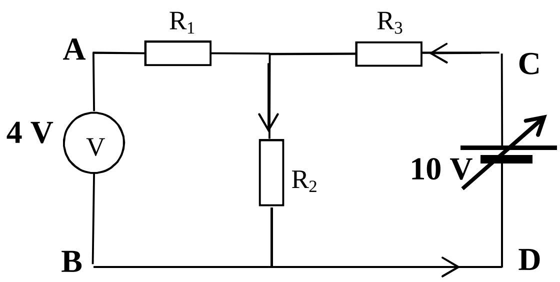
(*both marks if the correct answer)*

Total 4

Question 7.

a) **<u>Measurement 1</u>:** **<u>Measurement 2</u>:**





Measurement 1:

8 V, 5 V marked ✓

Arrows to show that the current is only in the left hand loop i.e. not through R_3. ✓

Measurement 2:

Correct circuit diagram (do not need a cell/supply if voltages noted) ✓

Required: 10 V, 4 V marked and the arrows to show that the current is only in the right hand loop i.e. not through R_1. Mark lost for a missing item. ✓

[The diagrams must contain the information to enable the calculation to be done]

[4]

b) Measurement 1: Left hand loop $8 = 0.5\,(R_1 + R_2)$ ✓

Across R_2 $5 = 0.5\,R_2$ ✓

Measurement 2: (same current in each resistor)

$$\frac{R_2}{R_3 + R_2} = \frac{4}{10}$$ ✓

c) To give $R_1 = 6\ \Omega$ ✓

$R_2 = 10\ \Omega$ ✓

$R_3 = 15\ \Omega$ ✓

[6]

Total 10

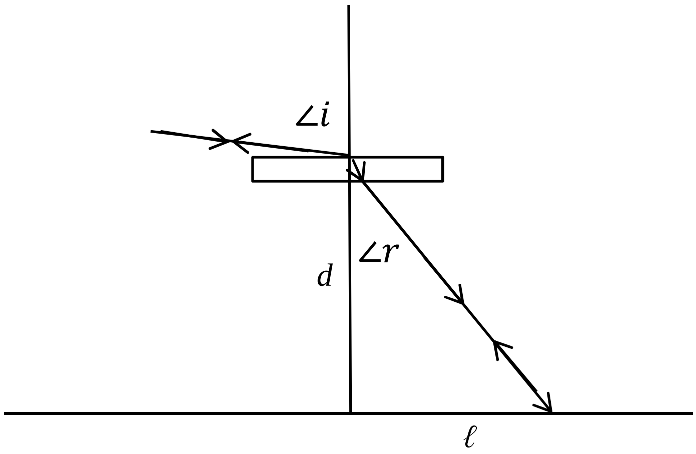
Question 8.

a) A diagram similar to the one below. ✓

Details of the light within the glass of the porthole are not required.

It should have the angle in the air greater than the angle within the water $i > r$. ✓

It may have the rays offset to the edge of the porthole as (ℓ + radius of porthole) will be needed in part (b).



[2]

b) Glass is thin so any sideways offset within the glass can be ignored

$$n = \frac{\sin i}{\sin r}$$

$$1.33 = \frac{\sin 90°}{\sin r_{max}} = \frac{1}{\sin r_{max}}$$

✓

$$r_{max} = 48.8° \ (= 49°)$$ ✓

$$R = d\tan(r_{max})$$
$$R = 4.0\tan 48.8 = 4.56 \text{ m} (= 4.5)\text{m}$$

(both of above mark for getting R without evaluating r_{max})

radius of circle of view = 4.56 + 0.1 m ✓

Hence area of view = $\pi r^2 = 68 \text{ m}^2$ ✓

(Without the 0.1 m porthole radius the area is 65 m^2, so only one of the marks).

[4]

Total 6

Question 9.

a) Equilibrium is a state of a system on which there is no resultant force and no resultant torque (or turning force). ✓ ✓

Alternative: a system that has no acceleration of the centre of mass and rotates at a constant rate about the centre of mass.
A system that has a constant velocity and rotates at a constant rate.

(owtte)

b) The plank will remain balanced ✓

As the student walks, by Newton's 1st Law (or can argue from 2nd) there is no resultant external force acting and so the centre of mass remains in the same place (above the top of the column) ✓

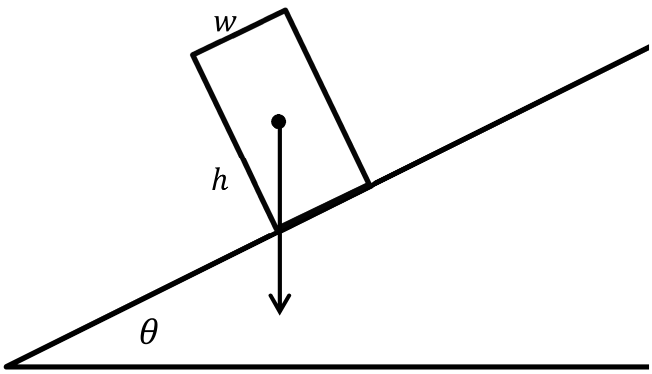
c) If the ball is given a small displacement from its equilibrium position ✓

In stable equilibrium it will return to the equilibrium position
In unstable equilibrium it will continue to move away from the equilibrium position. ✓

(one of the conditions may be implied in the wording of the other)

Do not accept it will roll off the inverted bowl. (It won't if it is in equilibrium on top – it needs an initial displacement).
Answers could speak of the GPE of the centre of mass, but must state whether the ball returns to the equilibrium position / moves further from the equilibrium position when the C of M is displaced. (the lowering of the C of M when displaced from the equilibrium position is a sign of unstable equilibrium, but it is the direction of the resultant force that continues to pull it away from the equilibrium position). **[6]**

d) Argument through diagram or statement ✓



Tipping occurs when the centre of mass lies above the bottom corner about which the block would turn.

$$\tan\theta = \frac{w/2}{h/2} = \frac{w}{h}$$ ✓

[2]

e)

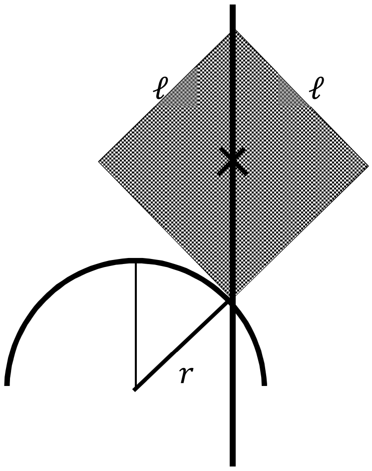


Diagram used or drawn. ✓

When the block rolls round an arc of length $r\frac{\pi}{4}$,

State/show that the arc length of $\frac{\ell}{2}$ must be equal to $r\frac{\pi}{4}$ ✓

So it will have a side parallel to *r* as in the diagram

means that the block has rotated by $\frac{\pi}{4}$ or 45^{o}

or $\frac{\pi}{2}$ or 90^{o} full range. ✓

Clear indication that centre of mass lies above the bottom corner ✓

[4]

f)

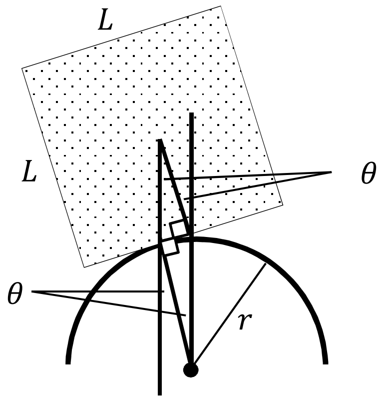


Diagram used/annotated or drawn. ✓
Angle θ marked in cube and in cylinder ✓

Balanced if centre of mass lies above point of contact.

Arc length = opposite side of right angle triangle ✓
(pointed out on diagram or just used)

Or written in the form $\frac{L}{2}\tan\theta = r\theta$

Or $L = 2r\frac{\theta}{\tan\theta}$

So that <u>$L = 2r$</u> ✓

[as $\frac{\theta}{\tan\theta} \to 1$ when $\theta \to 0$]

[4]

Total 16

Question 10.

a)

$$f = {}^{c}/_{\lambda}$$

$$f = 5.46 \times 10^{14} \text{ Hz}$$ ✓

$$E_{\text{ph}} = h\,{}^{c}/_{\lambda} = hf$$

$$E_{\text{ph}} = 3.6 \times 10^{-19} \text{ J}$$ ✓

Given that $n_{\text{E}} = 3.6 \times 10^{21} \text{ m}^{-2} \text{ s}^{-1}$

Inverse square law result: $\frac{n_{\text{J}}}{N_{\text{E}}} = \frac{R_{\text{E}}^2}{R_{\text{J}}^2} = \frac{150^2}{780^2}$ so that $n_{\text{J}} = \frac{n_E}{5.2^2}$ ✓

$$n_{\text{J}} = 1.3 \times 10^{20} \text{ m}^{-2} \text{ s}^{-1}$$ ✓

(Not needed, but $n_{\text{J}} E_{ph} = 48 \text{ W m}^{-2}$ and $n_{\text{E}} E_{ph} = 1300 \text{ W m}^{-2}$)

At Jupiter the force on the satellite is $F_{av} \times A$ which is $m_{sat} \times a$ ✓
(the question assumes that the gravitational force on the satellite is negligible for this mass)

Thus

$$m_{sat} \times a = F_{av} \times A = \frac{2n_{\text{J}} E_{ph} A}{c}$$ ✓

rearranging

$$A = \frac{m_{sat} a c}{2n_{\text{J}} E_{ph}}$$

$$A = 0.56 \times 10^{6} \text{ m}^2$$ ✓

$$(A = 750 \times 750 \text{ m}^2)$$

(There may be some small rounding errors in the values in the calculation. These are not critical)

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

[7]

b) The gravitational force of attraction of the Sun increases with the mass of the satellite. ✓

(The light pressure on the sail does not depend on the mass of the satellite.)

Or: with five times the mass, the gravitational pull will be similar in strength to the light pressure.

Closer to the Sun, the light pressure increases (as $1/r^2$), but so does the pull of gravity. (owtte) ✓

[2]

Total 9

END OF SOLUTIONS