BPhO
British Physics Olympiad

AS CHALLENGE PAPER March 2018 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 that 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. These are problems, not mere questions. Students should be awarded for progress, even if they do not make it quite to the end point, as much as possible. Be consistent in your marking.

The worded explanations may be quite long in the mark scheme to help students understand. Much briefer responses than these solutions would be expected from candidates.

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. The mark scheme often give 2 or 3 sf: either will do.

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

There is 1 mark for each correct answer.

Maximum 5 marks

Multiple Choice Solutions

Qu. 1 A physicist should learn to develop an approach to measurement.

Qu. 2 Units: $R = \frac{V}{I}$ which gives $\frac{\mathrm{J}}{\mathrm{CA}} = \mathrm{kg}\frac{\mathrm{m}^2}{\mathrm{s}^2}.\frac{1}{\mathrm{As.A}} = \frac{\mathrm{kg\ m}^2}{\mathrm{s}^3\ \mathrm{A}^2}$

Qu. 3 The dimensions or units on both sides of the equation must be the same. i.e. it must be dimensionally homogeneous. There is a speed on the LHS and not mass term, so we need to see how to eliminate the mass units on the right. That is in D in which the ratio of two masses is taken, and we are left with a speed squared term divided by a speed (at).

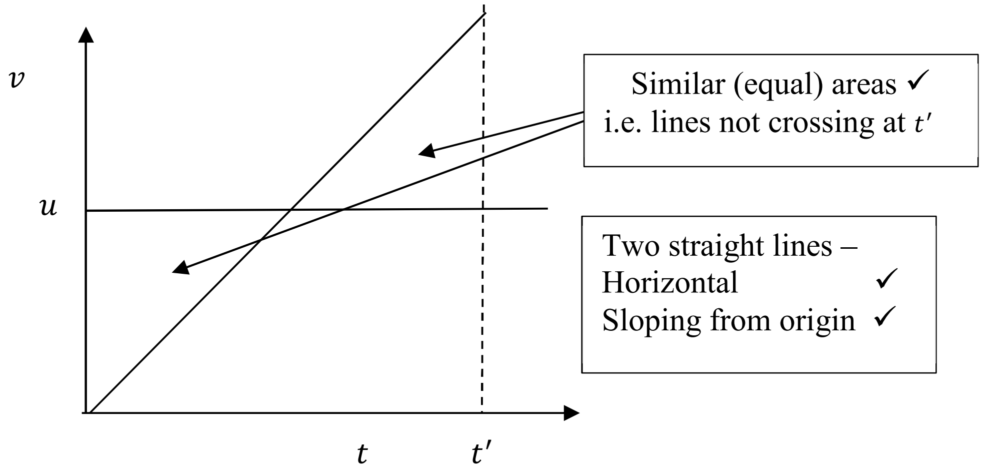
Qu. 4 Atoms are small. The scale factor linking atomic scales with everyday measurements is the Avogadro constant of ~ 10^{23} . 10^{8} is a very small number of molecules, and 10^{46} is Avogadro's number of Avogadro's numbers – an enormous amount.

Qu. 5 When an object is placed in a beaker of water it may float or sink, but there is an upthrust, buoyancy force, a tendency to float. Hence, with the finger in the liquid, the liquid is pushing up, and the finger is therefore pushing down on the liquid (Newton III). Hence, the balance reading will be greater. The reading does depend on the depth of the finger, but whether it increases or decreases (D) does not.

Section B: Written Answers

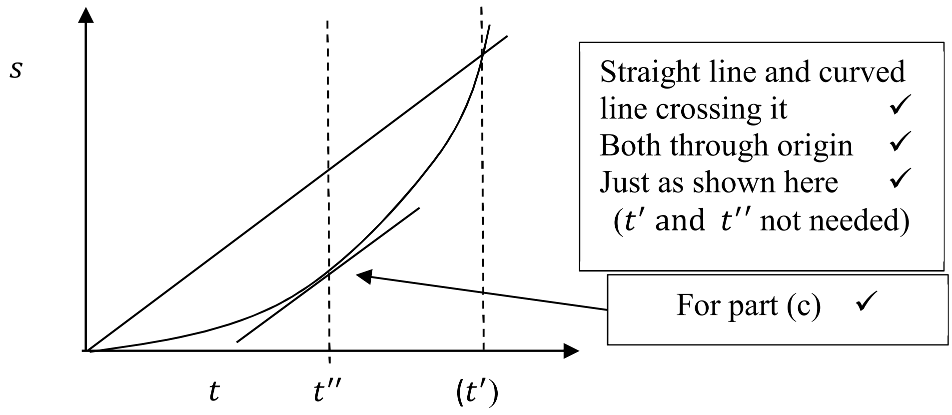
Question 6.

a)



[3]

b)



[3]

c) t'' marked (near) where the gradients are similar. ✓

When the motorbike is still slower than the car, the car is getting away. When the motorbike is faster than the car, it is catching up. So the greatest separation occurs when the motorbike is just about to start catching up with the car. So the gradients (speeds) will be the same on the distance-time graph. Owtte. ✓

Other arguments may be presented:
In (a) the max separation (Δs_{max}) is when the areas under the graphs are most different. i.e. at the moment when the speed graphs cross. This is at $\frac{t'}{2}$ which is halfway along the graph to when the vehicles pass. They pass when $ut' = \frac{1}{2}ft'^2$ so that $t' = \frac{2u}{f}$ and thus $t'' = \frac{1}{2}\frac{2u}{f} = \frac{u}{f}$ **[2]**

d) Any correct method allowed. But reasoning clear as it is a "show that"

For the motorbike, $v_{\text{MB}} = (v_0 = 0) + ft = ft$
And this is equal to the car's constant speed u ✓

When $t = t''$ they have the same speed ✓
So $u = ft''$

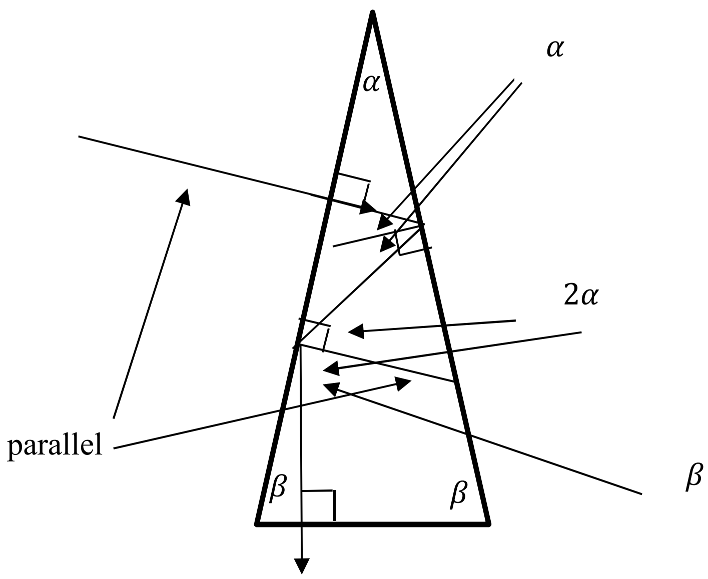
[2]

e) For the car, $s_{\text{c}} = ut$ in general so it has travelled $s_{\text{c}} = ut''$ at Δs_{max}.
For the motorbike, $s_{\text{MB}} = \frac{1}{2} f t''^2$
So $\Delta s_{\text{max}} = ut'' - \frac{1}{2} f t''^2$ *or progress towards this result* ✓
Substituting $t'' = \frac{u}{f}$ from (c) we obtain $\Delta s_{\text{max}} = \frac{u^2}{2f}$ ✓
Avoid spurious arguments about them travelling the same distance

[2]
Total 12

Question 7.

a)



b)
Isosceles prism ✓
The ray entering and leaving at normal incidence and two reflections ✓

[2]

Some angles marked ✓
Several approaches. Need some reasoning not just an answer without some indication of its origin.

At the bottom end we have $2\alpha = \beta$
From the triangle $\alpha + 2\beta = 180°$ ✓
So that $5\alpha = 180°$
And $\alpha = 36°$ or $\beta = 72°$ (accept either answer - only one needed) ✓

Award **3/3** if 36° written as long as it appears to have some kind of derivation and not been copied.

[3]
Total 5

Question 8.

a)
Using $v^2 = 2as$
with $a = 25g = 25 \times 9.81 = 245$ m s^{-2}
$s = 8.0$ m
Hence $v^2 = 3924$
And $v = 62.6 = 63$ m s^{-1} ✓

[1]

Or by energy, $\frac{\text{WD}}{m} = \frac{mad}{m} = ad = \frac{\frac{1}{2}mv^2}{m} = \frac{1}{2}v^2$
So $25 \times 9.81 \times 8.0 = \frac{1}{2}v^2$
Then $v = 62.6 = 63$ m s^{-1}

b) Maximum height is height fired + 8.0 m of tube.
Using $v^2 = u^2 + 2gh$
$0 = 3924 - 2 \times 9.81h$ resulting in $h = 200$ m ✓
So max height above ground is 208 m ✓

[2]

c) Using $v = u + at$
$t_{\text{up}} = \frac{62.6}{9.81} = 6.4$ s ✓
Or $s = \frac{1}{2}gt_{\text{up}}^2$ giving $200 = \frac{1}{2}9.81\, t_{\text{up}}^2$ resulting in $t_{\text{up}} = 6.4$ s
And

$s_{\text{down}} = \frac{1}{2}g\, t_{\text{down}}^2$ so that $208 = \frac{1}{2} \times 9.81\, t_{\text{down}}^2$
Hence $t_{\text{down}} = 6.5$ s ✓
Weightlessness is experienced going up and down. So total time is 12.9 = 13 s ✓
If the values are wrong, one mark (✓) for realising that weightlessness occurs during up and down motion.
Two marks if length of tube ignored and 12.8 (= 13 s) obtained

[3]
Total 6

Question 9.

a) A potential divider circuit
$\frac{V_{\text{AB}}}{R_2+R_3} = \frac{\varepsilon}{(R_1+R_2+R_3)}$ potential divider idea or equivalent approach ✓

So $V_{\text{AB}} = 4.5 \times \frac{700}{900} = 3.5$ V ✓
One mark for working out the current of 5 mA = 5×10^{-3} A, or writing down a correct equation for the circuit

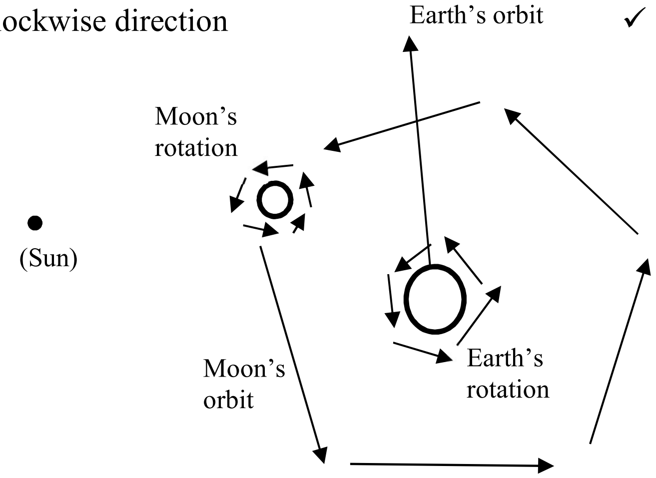
[2]

b) Similar potential divider
300 Ω and 400 Ω in parallel with 500 Ω to give 292 Ω ✓
Potential between AB is $V_{\text{AB}} = 4.5 \times \frac{292}{200+292} = 2.67\text{ V} = 2.7\text{ V}$ ✓
One mark for writing down a correct relevant equation (Kirchhoff)

[2]
Total 4

Question 10.

a) Clear labelled diagram with anticlockwise direction ✓



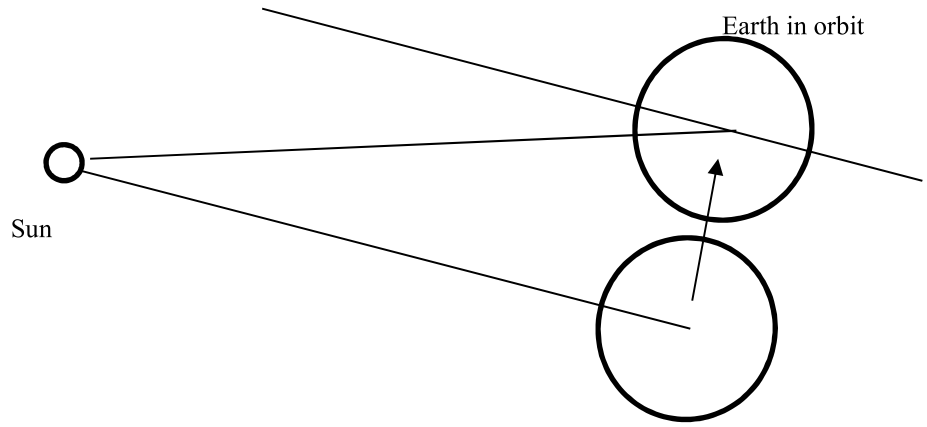
Sun not actually needed

[1]

b) Whilst the same side of the Moon always faces the Earth, the far side will sometimes be facing the Sun and sometimes the dark of outer space, as the Moon orbits the Earth. Statement must include the orbital aspect of the motion. ✓

[1]

c) Need a diagram to work with ✓



As the Earth orbits the Sun, it has to rotate a little further than 360° each day to observe the Sun overhead at noon. ✓

A point on the Earth rotates by $360° + \frac{360°}{365.25}$ in one 24 hour day since it makes one extra rotation in a year of 365.25 days. ✓

So to rotate only by 360° will take proportionately less time

i.e length of a sidereal day is (in minutes)

$$\frac{360}{360°+\frac{360°}{365.25}} \times 24 \times 60 \text{ minutes}$$

$$= \frac{1}{1+\frac{1}{365.25}} \times 24 \times 60 \quad \text{minutes}$$

$$= \frac{365.25}{366.25} \times 24 \times 60 \text{ minutes}$$

$$= 1436.07 \quad \text{minutes}$$
$$= 23 \text{ h } 56.1 \text{ m}$$

Which is 3.9(3) minutes less than 24 hours. Answer of 3.9 is correct. ✓

(or accept the length of a sidereal day given above)

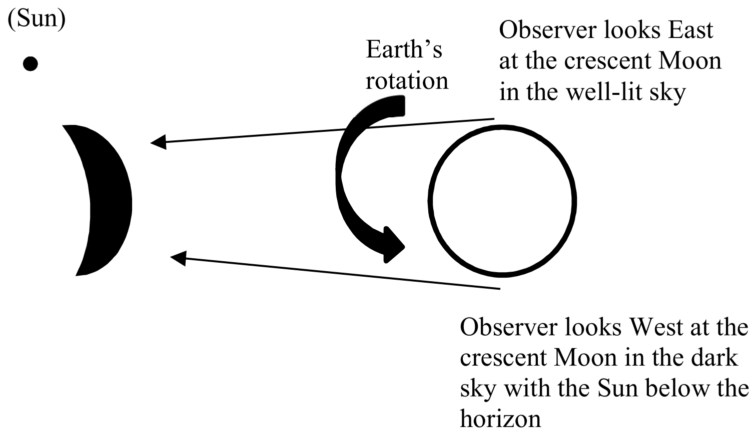
Or the calculation may be:

difference in length $= 24 \times 60 - \frac{365.25}{366.25} \times 24 \times 60 = 24 \times 60 \times \frac{1}{366.25} = 3.9(3)$ m

3 marks if they explain, but use $24 \times 60 \times \frac{1}{365.25} = 3.9(4)$ minutes

[4]

d) The new moon is between the Earth and the Sun. It is hard to observe as the bright Sun is behind it and it is daytime.
A few days later the Moon has moved round so that it is a little to the side of the Sun's position. A crescent is there to be seen, but not in daylight. As the Sun is observed to rise in the East, the crescent Moon will be there in the Eastern sky, but during daylight. As the Earth rotates, the observer will observe a dark sky late in the day, the Sun will have set in the West, and he will be able to observe the crescent Moon after the Sun has set, in a dark sky, a few minutes before the Earth rotates further and the crescent Moon sets also.



Credit for a clear argument ✓ with diagram ✓

[2]

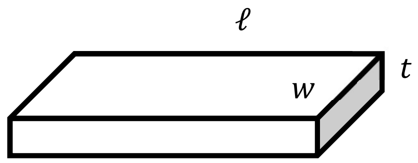
Total 8

Question 11.

a) Answer in the range 7 – 9 mg/cm^2 (unit required) ✓

[1]

b) For mass density ρ, $\frac{m}{w\ell} = \frac{\rho w \ell t}{w\ell} = \rho t$



"analysis" ✓

So 8 mg/cm^2 converts to $t = \frac{8\times10^{-3}}{4.1} = 1.95\times10^{-3}$ cm
$= 1.95\times10^{-5}$ m
$= 19.5\times10^{-6}$ m
= 19.5 µm converted value from (a) ✓

7 – 9 mg/cm^2 converts to 17 – 22 µm thickness

[2]

c) Substitution gives 2.2×10^{-3} cm = 22 µm ✓
Sensible comment comparing to (b) result ✓

[2]

d) The β radiation is very penetrating and most of the β pass through the phosphor. ✓
OR The thicker the phosphor is, the more the β interact and more light is emitted.

The alpha have a limited range and the thicker phosphor surface stops them all shortly after entering the phosphor, so that much of the light is then absorbed in the remaining phosphor if it is made thicker.
i.e. thicker phosphor absorbs the light produced by the alpha ✓

[2]

e) Efficiency = power out / power in
Five cells power input is 5×2.15 mW ✓
Efficiency = $\frac{21\times10^{-6}}{5\times2.15\times10^{-3}} = 0.2$ % ✓

The internal resistance will be given by the emf/short circuit current (for a well behaved cell)
$r = \frac{2.3}{14\times10^{-6}} = 160$ kΩ ✓

[3]

Total 10

END OF SOLUTIONS