SENIOR PHYSICS CHALLENGE
March 2023
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 on a technical point, email rh584@cam.ac.uk .

A positive view should be taken for awarding marks for 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.

Benefit of the doubt is NOT to be given for scribble.

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 3 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, or even less. If there is some modest rounding error in their answer then give them the mark. There is time pressure and so if they are on track for the answer then award the mark.

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. **A**
Question 3. **E**
Question 4. **D**

There is 1 mark for each correct answer.

Qu. 1 $N \approx 40 \times \frac{10^6}{\pi \times 0.8} \approx 10^7$

Qu. 2 Using $p = \rho g h$ the pressure at the depth of a column of liquid is only dependent on the height of the liquid above, not on the width of the vessel.

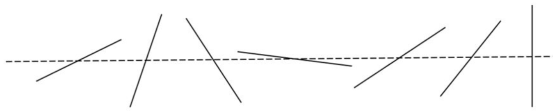
Qu. 3 Wavelength is 2 m. So there are 78 wavelengths and 1m or $\frac{\lambda}{2}$ left over.

Qu. 4 With constant acceleration, the up ball comes down to the level of the girl, at the same speed as it was thrown upwards.

Total 4

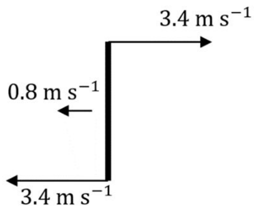
Question 5.

(a) i.



it goes from right to the left ✓
the centre move along a straight line ✓
it rotates about the centre point of the rod ✓
[3]

ii.



speed of centre is $\frac{4.2 - 2.6}{2} = 0.8$ m/s ✓
[1]

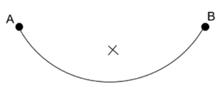
iii.

$$f = \frac{1}{T} = \frac{speed}{distance} = \frac{3.4}{2\pi \times 0.17}$$

use of 3.4 m/s ✓
3.2 Hz ✓
[2]

iv. velocities of 3.4 and 0.8 m/s perpendicular. ✓
So Pythagoras to obtain 3.5 m/s ✓
[2]

(b) i.



✓
[1]

ii.

- Work is Done when F is applied ✓
- As cable is pulled lower other parts rise ✓
- So the centre of mass goes higher ✓

[3]

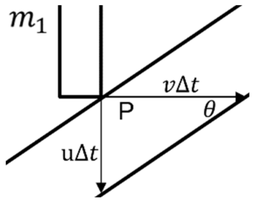
Total 12

Question 6.

(a) Constant acceleration ✓

[1]

(b)



(u, v changing but Δt small)
Diagram or working ✓
$\tan(\theta) = \frac{u}{v}$ ✓

[2]

(c) $\frac{1}{2}m_2v^2 + \frac{1}{2}m_1u^2 = m_1gh$ lose a mark for a mistake ✓✓

[2]

(d) $v^2(m_2 + m_1\tan^2\theta) = 2m_1gh$ lose a mark for a mistake ✓

[1]

(e) $m_1 = m_2,\ \ \theta = 30°$ then $v^2\left(1 + \frac{1}{3}\right) = 2gh$

$$v^2 = \frac{3}{2}gh$$

Loss of rod is mgh

Gain of wedge is $\frac{1}{2}mv^2 = \frac{3}{4}mgh$

Fraction passed to wedge is $\frac{3}{4} = 75\%$ ✓

[1]

(f) $u = v\tan\theta$

$$u = \sqrt{\frac{2m_1gh\tan^2\theta}{m_2 + m_1\tan^2\theta}}$$

For constant acceleration from rest, $u^2 = 2as$ recognition of this idea ✓
So that

$$a = \frac{m_1g\tan^2\theta}{(m_2 + m_1\tan^2\theta)}$$

✓

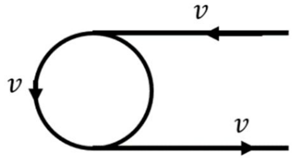
[2]

If they have applied the values of part (e) then they get the **<u>two marks</u>** if they have used the [idea for $u^2 = 2as$] ✓ and perhaps gone through the route $\frac{1}{2}mu^2 = \frac{1}{4}mgh$ for the rod, so that $u^2 = 2as = \frac{1}{2}gh$ giving $a = \frac{g}{4}$ ✓

<u>Total 9</u>

Question 7.

The track moves around the wheel at speed v. If the speed of the track on the ground is zero (it does not slide) then the top track must be moving at $2v$ with respect to the ground. ✓



Add v acting to the left to make the speed on the ground zero and the speed on the upper track $2v$. ✓

Speed of the wheel circumference is

$$v = \frac{\pi d}{T} = \frac{\pi \times 1}{0.84} = 3.74 \text{ m/s}$$ ✓

So the speed of the mud is $7.48 = 7.5$ m/s ✓

[4]

<u>Total 4</u>

Question 8.

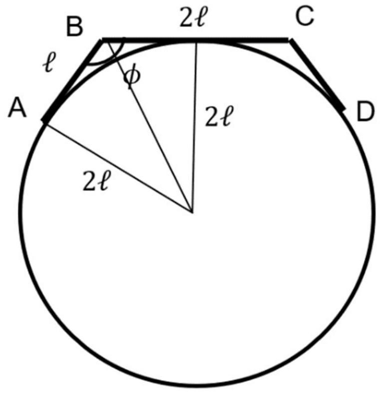


Diagram has to be drawn ✓

Approximate ratio for radius to rod lengths ✓
Correct angle $\angle ABC$ considered ✓

$$\tan\frac{\phi}{2} = \frac{2\ell}{\ell} = 2$$

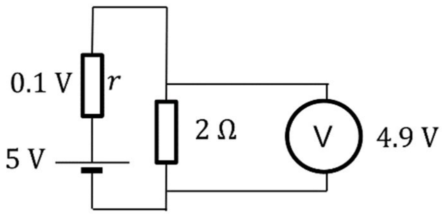
$$\phi = 127°$$ ✓

[4]

Total 4

Question 9.

(a) i.

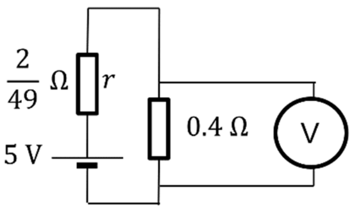


Identify potentials ✓

$I = \frac{4.9}{2} = \frac{0.1}{r} \rightarrow r = \frac{0.2}{4.9} = \frac{2}{49}\ \Omega = 0.041\ \Omega$ ✓

[2]

ii.



$I = \frac{V}{0.4} = \frac{5}{0.4+\frac{2}{49}}$ or similar idea ✓

$V = \frac{2\times 49}{0.4\times 49+2} = \frac{98}{21.6} = 4.54\ \text{V}$ ✓

[2]

(b) Case 1 with voltmeter present

$$I_{\text{R}} = 0.3 + 0.4 + 0.9\ \text{mA}$$
$$= 1.6\ \text{mA}$$
$$\therefore R = \frac{240-90}{1.6\ \text{mA}} = \frac{150}{1.6}\ \text{k}\Omega$$ ✓

Case 2 without voltmeter

$$I = \frac{240-V}{R}$$

And $I - 0.4\ \text{mA} = \frac{\text{V}}{100\ \text{k}\Omega}$ ✓

Equating $\frac{240-V}{\left(\frac{150}{1.6}\text{k}\Omega\right)} - 0.4\ \text{mA} = \frac{\text{V}}{100\ \text{k}\Omega}$

Evaluating $\frac{240}{75\ \text{k}\Omega} \times 0.8 - \frac{0.8V}{75\ \text{k}\Omega} - 0.4\ \text{mA} = \frac{V}{100\ \text{k}\Omega}$

$$\frac{48}{15000} \times 0.8 - \frac{0.4}{1000} = V\left(\frac{1.6}{150\,000} + \frac{1}{100\,000}\right)$$

$$V = 104.52 = 105\ \text{V}$$ ✓

[3]

Total 7

Question 10.

(a) $[\mathrm{C}] = \mathrm{Pa.m^3} = \mathrm{Nm} = \mathrm{J} = \mathrm{kg.m^2.s^{-2}}$ ✓

[1]

(b) $P_m = 2 \times 10^4 \frac{dyne}{cm^2} = 2 \times 10^4 \left\{\frac{ma}{area}\right\} = 2 \times 10^4 \times \frac{10^{-3} \times 10^{-2}}{10^{-4}} \frac{N}{m^2}$

$= 2 \times 10^3 \text{ Pa}$ ✓

[1]

(c) 2 - 4 cm: $\Delta V = \frac{4}{3}\pi(4^3 - 2^3) \times 10^{-6} = 2.35 \times 10^{-4} \text{ cm}^3$

and $P_{av} = 1.8 \times 10^3$ Pa

So WD = 0.42 J ✓

4 - 6 cm: $\Delta V = \frac{4}{3}\pi(6^3 - 4^3) \times 10^{-6} = 6.37 \times 10^{-4} \text{ cm}^3$

and $P = 1.3 \times 10^3$ Pa

WD = 0.83 J ✓

Total ≈ 1.3 J

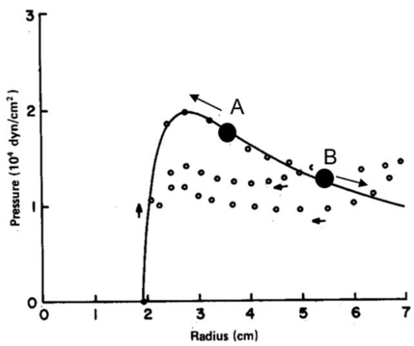
[2]

(d) Differentiate $r_m = \sqrt[6]{7}.r_0$ ✓✓

[2]

(e) i.

If the two balloons sit on the sloping shoulder to the right of the peak, then the



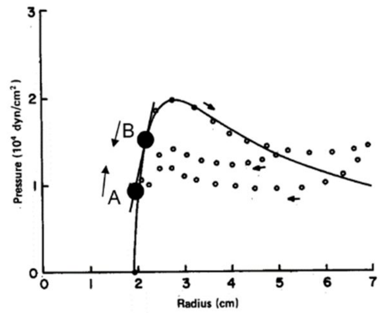
higher pressure A sits on the left and the lower pressure B, with the larger radius, on the right. The HP balloon, A, pushes air into the LP one B, so that B has more air in it and it radius increases although its pressure still decreases. The HP balloon, A, moves to the left as it shrinks with less air, but with increased pressure, and so its radius decreases and pressure increases until it moves over the peak travelling to the left. Then the pressure will reduce as it goes down the steep slope and it ends up at an equal pressure to B, as it almost empties itself.

It does not matter if A starts on the left of the peak, as long as B has a lower pressure to begin with.

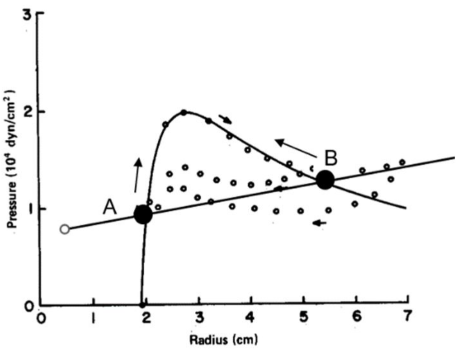
Some explanation and the result. **[2]**

ii.

Case 1. Both balloons on the left side of the peak (little air in them). The smaller radius low pressure balloon rises up the slope whilst the other moves down the slope and they meet at equal pressures, with **<u>equal radii</u>**, both the on the LHS of the peak.



Case 2. Smaller radius balloon on the LHS of the peak, and larger radius HP balloon on the RHS of the peak (a line joining the balloons slopes down to the left). As A rises up the slope, B rises slowly up, and then they can reach equal pressures with B still on the RHS, so that they remain on different sides of the peak with **<u>different radii</u>**.



If there is rather less air in B, then B will inflate A, but B could slip to the left, over the peak so that they both end up on the LHS of the peak at small but **<u>equal radii</u>**.

So, for e(ii), **<u>the radii may end up equal or unequal</u>**. It depends on the volume of air in the balloons as to whether they both end up on the left side or opposite sides of the peak of the graph.

The lower pressure balloon can never jump over to the RHS of the peak.

Some explanation and the result.

[2]

<u>Total 10</u>

END OF SOLUTIONS