SENIOR PHYSICS CHALLENGE
March 2025
SOLUTIONS

Some corrections made, noted in red. Friday 7th Mar 16:00.

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. However, there are several questions where the initial answers are easily obtained an if they are wrong then there is no reason to do a lot of ecf. They should get easy questions right.

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

Section A: Multiple Choice

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

[12]

Q1. Correct dimensions requires A

Q2. $d = \frac{2\times10^3\times10^7\times10^6}{\frac{4}{5}\times4\pi(6.4\times10^6)^2} = \frac{2\times10^{16}}{4.1\times10^{14}} = 50 \text{ m}$ (factor 4/5 is area covered by ocean)

Q3. Volume approach:

$$\ell = width \times \frac{(\pi R_{outer}^2 - \pi R_{inner}^2)}{width \times thickness}$$
$$= \frac{\pi(0.06^2 - 0.02^2)}{0.2\times10^{-3}}$$
$$= 50 \text{ m}$$

Circumference approach

$$\ell = 2\pi \times R_{average} \times no.of\ layers$$
$$= 2\pi \times 0.04 \times \frac{0.04}{0.2\times10^{-3}}$$
$$\approx 50 \text{ m}$$

Hence $T \approx 50$ s

Q4. Since the angle is the same, the vertical (time of flight determining factor) $v \sin\theta$ will be twice as large, and with $v = gt$ the time of flight will be twice as long.
Then the Range will be twice the horizontal speed × twice the time of flight, so four times as far.

Q5. 'Pizza Box' Milky Way: volume, $V = (10\ )\times 10\ = 10^{13}$ Ly^3
Give each star a volume of space x , where x is the average distance between stars.
Number of stars in galaxy, $N = \frac{V}{x^3} = 10^{11}$

$x = \left(\frac{V}{N}\right)^{\frac{1}{3}} = \left(\frac{10^{13}}{10^{11}}\right)^{\frac{1}{3}} = 4.6$ Ly (actual number is, with much uncertainty, about 5 Ly)

Q6. Correct dimensions, although this can be worked out from the forces and a differentiation.

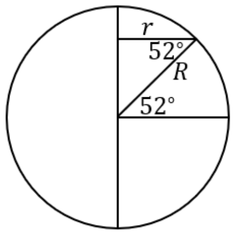
Q7 falling object: $s = \frac{1}{2}gt^2$ so $t_{up} = \sqrt{\frac{2s}{g}}$ ✓

$$T_{flight} = 2t_{up} = 2\sqrt{\frac{2s}{g}} = 1.28 \text{ s} = 1.3 \text{ s}$$ ✓

Therefore speed of train = 4000 m / 100 × 1.28 = 31.3 = 31 m s^{-1} ✓

[3]

Q8



Direction of plane is to the West ✓

$r = R\cos(52)$ ✓

Speed $= \frac{s}{t} = \left(\frac{2\pi r}{T}\right)$

$= \frac{2\pi R\cos(52)}{T}$ ✓

$= 286 = 290$ m s^{-1} ✓

[4]

Q9 100 kg → 100 ℓ of water → 200 bottles ✓

So one side is $\sqrt{200}$ bottles $= 10\sqrt{2}$ bottles ✓

One 500 ml (cm^3) cuboid bottle has a side $\sqrt[3]{500}$ cm $= 10 \times 2^{-\frac{1}{3}} \approx 8$ cm ✓

So length of a side is

$10\sqrt{2} \times \sqrt[3]{500} = 10 \times 2^{\frac{1}{2}} \times 10 \times 2^{-\frac{1}{3}} = 100 \times 2^{\frac{1}{6}}$ cm $= 2^{\frac{1}{6}}$ m $= 1.12 = 1.1$ m ✓

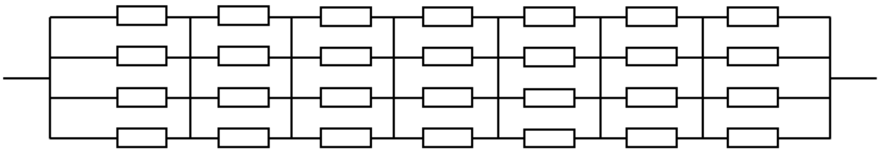
Or just total area $= 200 \times (0.08)^2 = 1.3$ m^2 giving a length of one side as 1.1 m

One mark for clarity – is it clear to you or not. ✓

[5]

Q10

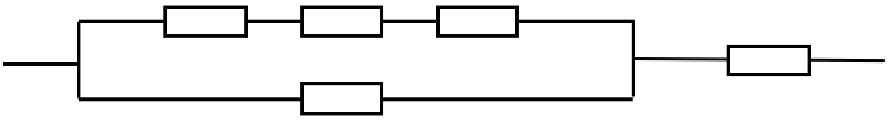
(a) Diagram such as:



Each vertical is 1 Ω and there are seven in series; or any arrangement which gives 7 Ω ✓

Fewer resistors than 28 ✓

(b) Some more efficient use of resistors, such as



More than five resistors, only 1 mark out of 2.

✓✓

[4]

Q11

(a) The bike pivots about the rear axle. When the bike is not moving forwards, the ground pushes the wheel forwards with a force F at radius r from the axle, and the bike engine lift the weight of the bike about this axle. ✓

As a result, the torques about the axle must balance if the bike is not to lift up. ✓

(If the bike accelerated forwards, not being essentially at rest, then the contact point with the ground would produce a large force forwards and the inertia of the bike would case it to tip backwards over the rear wheel – a slightly different situation to the one here where the bike starts from rest and the torque just rotates the bike about the axle).

(b) So take moments about centre of rear wheel: $F.R = W.X$ ✓

Hence $F = \frac{250 \times 9.8 \times 1.1}{0.35} = 7700$ N

This causes an acceleration of $\frac{7700}{250} = 31$ m s^{-2} ✓

(c) Using this acceleration, the time for 0 – 60 mph is:

$t = \frac{\Delta v}{a} = \left[60 \times \frac{1610}{3600}\right] \times \frac{1}{31} = 0.87$ s (rather a short time in fact) ✓

Correct conversion to m/s ✓

[6]

Q12.

(a) The rocket motor is switched off;

The rocket's momentum means that it will continual to travel, still rising ✓

But the resultant force of gravity acting will reduce its speed. ✓

(b) Using data from the last five points,

$u = 10^3 \text{ m s}^{-1}$

$v = 600 \text{ m s}^{-1}$

$s = 3.3 \times 10^4 \text{ m}$ Data ✓

Using $v^2 = u^2 + 2as$, $a = -9.7 \text{ m s}^{-2}$ ✓

Comment: acceleration is downwards ✓

Specifically point out the value is similar to freefall $g = 9.8 \text{ m s}^{-2}$, related to, ✓

e.g. there is air friction as it falls, but the air is of very low density ✓

or any sensible physics comment

(c) The friction with the atmosphere will depend on the velocity of the craft and also the density of the atmosphere at a given point. It will be largest when both of these are large. The density of the atmosphere decreases with height, so Max Q will be at a height with large velocity but low altitude.

AND accept anywhere from 30 – 50 km ✓

[8]

Q13.

(a) Speed of water increases as it falls owtte ✓

Volume flow per unit time at top = volume flow per unit time at bottom owtte ✓

(b) Mass of water per second at top of stream = mass of water per second at the bottom

$$v_1 \rho \frac{d_1^2}{4} = v_2 \rho \frac{d_2^2}{4}$$

So $$v_2 = \frac{d_1^2}{d_2^2} v_1$$ ✓

(c) Calculate the speed of the water:

Given $v_2^2 - v_1^2 = 2gh$

so that $v_1^2 \left(\frac{d_1^4}{d_2^4} - 1\right) = 2gh$ (some form of correct substitution) ✓

$$v_1^2 \left(\frac{5^4}{4^4} - 1\right) = 2 \times 9.8 \times 0.03$$

$$v_1 = 0.639 = 0.64 \text{ m s}^{-1}$$ ✓

(d) Volume rate of flow = Volume/second = $\frac{\pi d_1^2}{4} v_1$ ✓

$= 1.2547 \times 10^{-5} \text{ m}^3\text{s}^{-1}$

$= 12.5 \text{ cm}^3\text{s}^{-1}$ allow ecf ✓

(e) Time to fill a 200 cm^3 beaker.

Time taken = volume / rate of flow

= 200 /12.6

= 15.9 = 16 seconds allow ecf ✓

[8]

END OF SOLUTIONS