SENIOR PHYSICS CHALLENGE
March 2020
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. **C**
Question 3. **B**
Question 4. **E**
Question 5. **D**

There is 1 mark for each correct answer.

Maximum 5 marks

Multiple Choice Solutions

Qu. 1 The thickness of the film is very small compared to its areal dimensions i.e. the radius.
So $m = \rho V = \rho 4\pi r^2 \times t = 1000 \times 4\pi \times 0.1^2 \times 300 \times 10^{-9} = 4 \times 10^{-5}$ kg

Qu. 2 Vectors shown are components. So to add them they must be tip-to-tailed to obtain **V.**

Qu. 3 Time for an orbit is $\frac{\ell}{c}$,

so that $t = 9 \times 10^{-5}$ s. So $s = \frac{1}{2}gt^2 = 0.5 \times 9.8 \times 81 \times 10^{-10} = 4 \times 10^{-8}$ m.

Qu. 4 The principle covering all of these observations is that of **superposition**, in which the resultant displacement at a point is obtained by adding the displacements (obtaining the algebraic sum of the displacements - adding with the signs) or adding the vector components of the displacements, if you had horizontal and vertical wave (which we don't really have here).

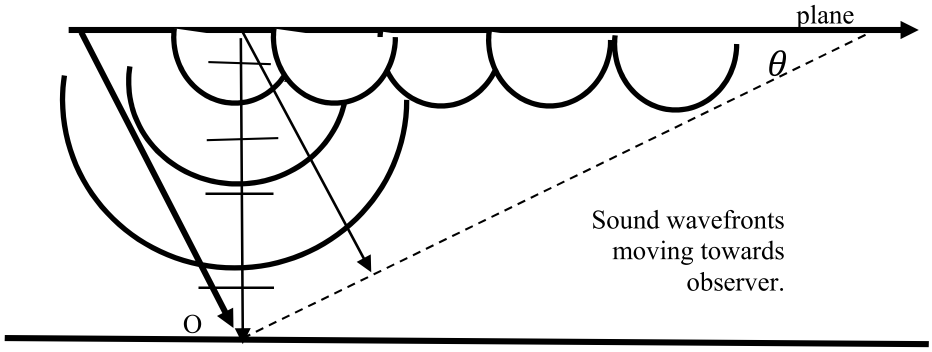
Qu. 5 Taking moments about the hinge at the wall, $\frac{mg\ell}{2} = T\ell \cos 40$ which evaluates to
$2g = T\cos 40$ and $T = 25.6$ N.

Total 5

Section B: Written Answers

Question 6.

Diagram essential.



A DIAGRAM ✓

The plane is continuously making sound. The sound wavefront moves down, but at an angle since later sound from the moving plane is emitted later on. When the plane is seen overhead, the sound will take time to travel to the ground, so the sound first heard is before the plane is overhead. Then how far has the plane travelled in this time? The heavy arrows are the equal times for sound and plane to travel. The dotted line is the wavefront, normal to the direction of sound travel.

An explanation ✓

$\sin\theta = \frac{v_{sound}}{v_{plane}} = \frac{1}{3} \quad (\theta = 19.5°)$ ✓

Minimum distance is given by the length of the sloping (dotted) line:

Which is $\frac{15}{\sin\theta}$ km

$= 15/(\frac{1}{3}) = 45$ km ✓

Total 4

Question 7.

Direction 1 mark and value one mark (direction can be given as an arrow, but must be unambiguous)

(a) Average velocity is total displacement / time taken.
average velocity is **ZERO** ✓

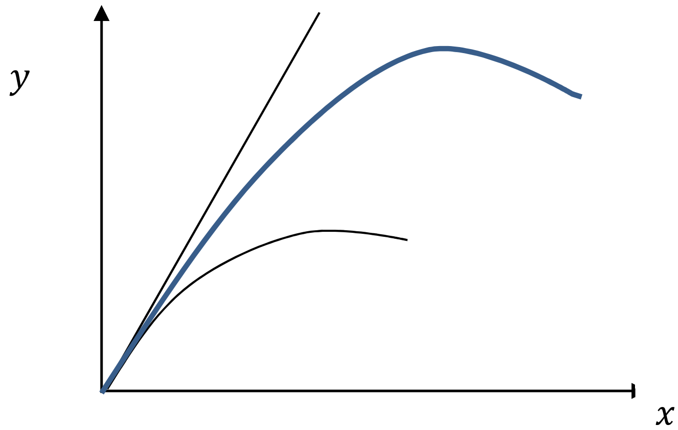
(b) From A to C the displacement is $2r$ SOUTH (never mind the path taken)
But time taken is path dependent, so that $t = \frac{\pi r}{v} = 1$ s
So the average velocity is **8 m/s SOUTH** ✓✓

(c) The displacement from A to B is **SOUTHEAST**, 135°, or drawn ✓
And Pythagoras on the diagonal line $\sqrt{r^2 + r^2} = \sqrt{2}r = 4\sqrt{2}$
Average velocity is $\frac{4\sqrt{2}}{0.5} = 8\sqrt{2} = 11.3$ = **11 m/s** ✓

Total 5

Question 8.

(a) **<u>1 mark for graph</u>**



- Need same initial angle.
- Higher peak is at the right of the lower.
- x and y on axes (not time)

(b) This is following the instructions. **2 marks for two or more correct equations**

θ is given as the angle to the horizontal.

$$x_1 = v_1 \cos\theta . t$$
$$y_1 = v_1 \sin\theta . t - \frac{1}{2} g t^2$$
$$x_2 = v_2 \cos\theta . t$$
$$y_2 = v_2 \sin\theta . t - \frac{1}{2} g t^2$$

(c) Subtract the x coordinates and the y coordinates. **2 marks for manipulating to these**

$$x_1 - x_2 = (v_1 - v_2)\cos\theta . t$$
$$y_1 - y_2 = (v_1 - v_2)\sin\theta . t$$

The line joining the balls is the "gradient" from these coordinates.
So divide the equations.

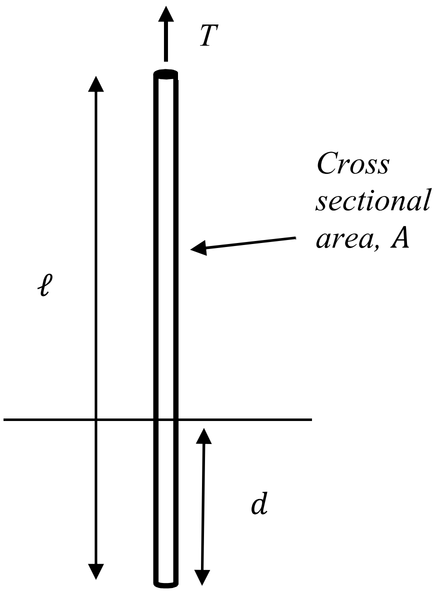
$$\frac{y_1 - y_2}{x_1 - x_2} = \tan\theta$$

1 mark for an expression of the result in some form

(The line joining them remains at a constant angle, the initial angle of launch.)

Total 6

Question 9.



Tension when not in water, $T_1 = A\ell\rho_r g$ ✓

Use of Archimedes idea: ✓

upthrust = weight of water displaced

Tension when dipped in water

$$T_2 = A\ell\rho_r g - A\ell\rho_w g \quad ✓$$

Given $\dfrac{T_2}{T_1} = \dfrac{5}{6}$

Hence $\dfrac{\rho_r\ell - \rho_w d}{\rho_r\ell} = \dfrac{5}{6}$ (or similar) ✓

(Cancelling the A and g terms)

Divide by ℓ

$$\frac{\rho_r - \rho_w \frac{d}{\ell}}{\rho_r} = \frac{5}{6}$$

And given $\dfrac{d}{\ell} = \dfrac{1}{4}$

Then $\rho_r - \rho_w \frac{1}{4} = \frac{5}{6}\rho_r$ and then $\frac{1}{6}\rho_r = \frac{1}{4}\rho_w$ giving $\frac{\rho_r}{\rho_w} = \frac{6}{4} = 1.5$ ✓

Total 5

Question 10.

Allow reasonable error carried forward. Answers can be rounded.

(a) In a cubic metre of sodium, there are $\dfrac{971\times10^3\ \text{g}}{23\ \text{g/mol}}$ = 42,200 moles ✓

No of atoms in this 1 cubic metre is $nN_\text{A} = 6.02 \times 10^{23} \times 42{,}200 = 2.5 \times 10^{28}$ ✓

In a cubic array of atoms, the length of a side of a single cube containing an individual atom is given by $(2.5 \times 10^{28})^{-\frac{1}{3}} = 3.4 \times 10^{-10}$ m ✓

(b) $E = hf = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{3.4\times10^{-10}} = 5.8 \times 10^{-16}$ J ✓

Allow ecf on λ

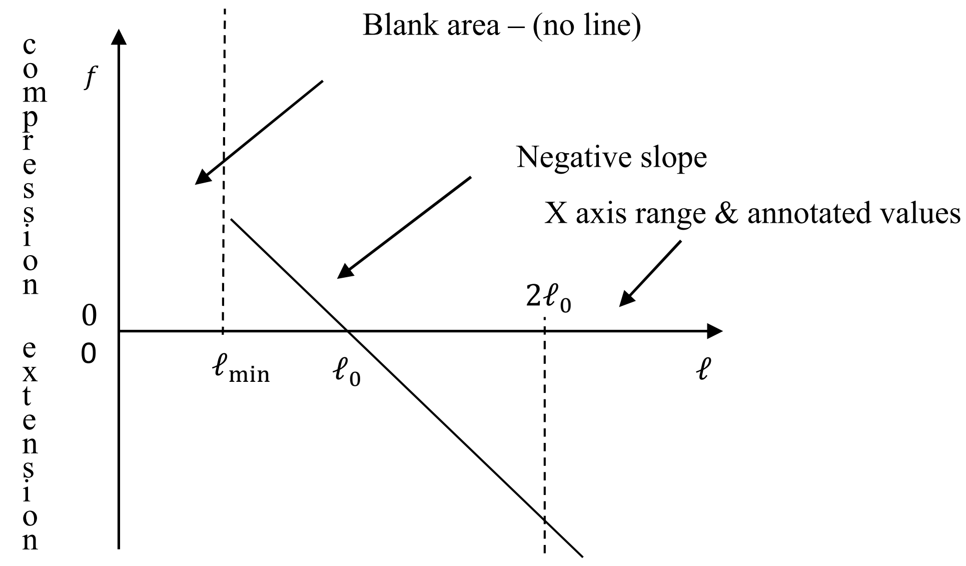
$(= \frac{5.8\times10^{-16}}{1.6\times10^{-19}} = 3.6 = 4$ keV$)$

(c) Voltage required is 4 kV ✓

Total 5

Question 11.

(a) 1 mark for graph with negative slope, 1 mark for annotations & blank ✓✓



(b) Area under graph is work done in stretching/compressing the spring. ✓
(area = ½ base x height), either side of the ℓ_0 point

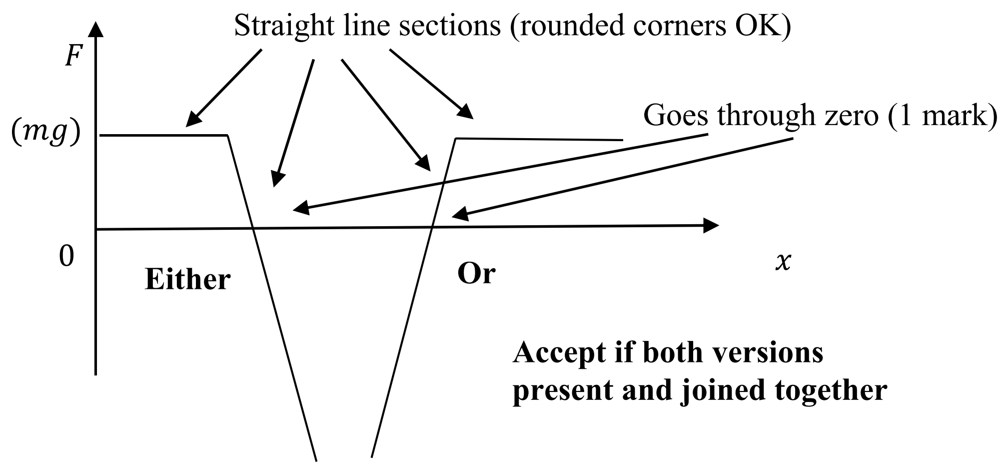
(c) Forces approach (not energy as that will introduce an extra factor of ½)

$$mg = k(\ell_0 - \ell')$$
$$mg = k\ell_0 f'$$
$$k = \frac{mg}{\ell_0 f'}$$

✓

(d) Graph with straight line aspects, goes through zero.

Horizontal before & after spring contact ✓
Graph can be inverted but still goes through zero. ✓



(e) Energy argument here.
GPE lost = elastic PE gained at lowest point. ✓

$$mg(\ell_0 - \ell) = \frac{1}{2}k(\ell_0 - \ell)^2$$
$$mg = \frac{1}{2}k(\ell_0 - \ell)$$
$$= \frac{1}{2}k\ell_0(1 - \frac{\ell}{\ell_0})$$

And with $k = \frac{mg}{\ell_0 f'}$ $\quad mg = \frac{1}{2}\left(\frac{mg}{\ell_0 f'}\right)\ell_0 f$

To give $\quad f = 2f'$ ✓

(f) The result will be the same apart from a minus sign.

$$f = -2f'.$$

The energy argument applies, as above, but the extension of the spring will be $(\ell - \ell_0) = \ell_0\left(\frac{\ell_0}{\ell} - 1\right) = -\ell_0 f$.

So a **mark for the same result** and a **mark for the minus sign** (unless they take f' to be the stetch of the spring with the ball resting in a hanging mode. But this would have to be clearly stated and not implied. ✓✓

Total 10

Question 12.

(a) $R = \frac{(5.0-1.8)}{24\times10^{-3}} = 130\ \Omega$ ✓

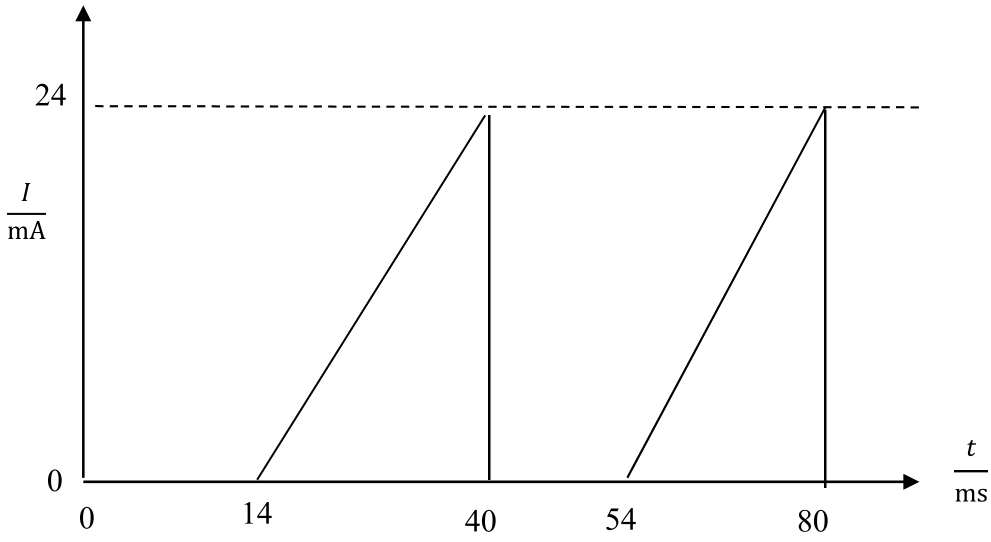
(b) $\frac{P_{LED}}{P} = \frac{1.8\times24\times10^{-3}}{5.0\times24\times10^{-3}} = \frac{1.8}{5.0} = 0.36$ ✓

(c) LED lit when $V > 1.8$ so it switches on

at a time $\frac{1.8\ (\mathrm{V})}{5.0\ (\mathrm{V})} \times 40\ \mathrm{ms} = 14.4\ \mathrm{ms} = 14\ \mathrm{ms}$ ✓

It is ON for a fraction of the time, given by $\frac{(5.0-1.8)}{5.0} = \frac{3.2}{5.0} = 0.64$ ✓

(d)



Values and "gaps" between peaks ✓

We need the average current x the voltage across the LED (either zero or 1.8 V).
The average current is given by the charge flow per cycle divided by the period.
The charge flow is the area under the $I - t$ graph (per cycle). (½ base x height) ✓

$$I_{av} = \frac{Q}{t} = \frac{\frac{1}{2}\times 24\times 10^{-3}\times(40-14.4)\times 10^{-3}}{40\times 10^{-3}} = 7.68\times 10^{-3}\text{A} = 7.7 \text{ mA}$$ ✓

Average power = $V \times I_{av} = 1.8 \times 7.68 \times 10^{-3} = 0.014$ W ✓

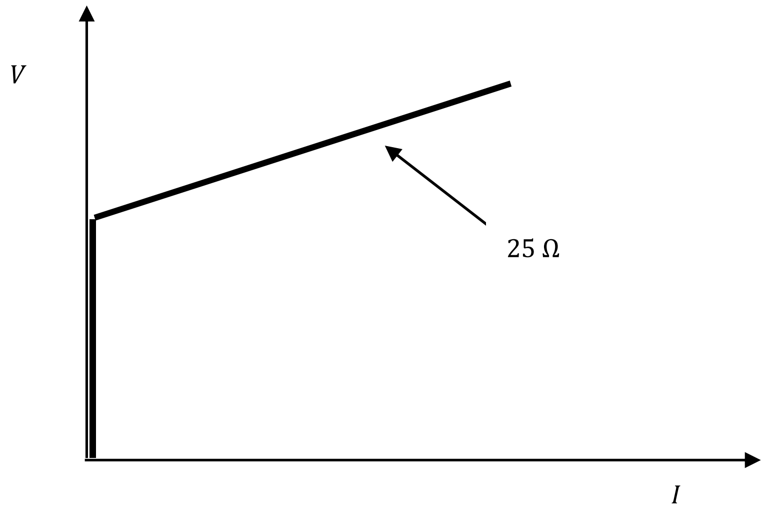
(exact numerical values not essential)

Or:

(fraction of) area under peak/total area x DC power ✓

= ½ (40 - 14.4) x 24 / (24 x 40) x 1.8 x 24 x 10^{-3} = 0.014 W ✓✓

(e) Gradient of graph is 40 mA/V.
Hence 10 mA means 0.25 V needed for resistive part of LED ✓
And added to 1.8 V of V_c gives 2.05 V. ✓



Or:

From this graph, we can use the equation for the straight line for the sloping part,
$y = mx + c$ ✓

$$V = V_c + 25I$$
$$= 1.8 + 25 \times 10 \times 10^{-3}$$
$$= 2.0(5) \text{ V}$$ ✓

Total 10

END OF SOLUTIONS