British Physics Olympiad

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BPhO Physics Challenge - Mark Scheme

September/October 2021

Instructions **Give equivalent credit for alternative solutions which are correct physics. Generally allow leeway of ± 1 significant figure.**

This is not the tight marking scheme of a competitive exam paper. It is to allow students to engage in problem solving and develop their physics by working through problems requiring explanations, and developing ideas or models. Mark generously to encourage ideas, determination and the willingness to have a go.

Qu 1.

As these are estimates the calculations below simply show one way to tackle the task; a good deal of latitude is needed in the marking to allow equivalent credit for other sensible approaches and degrees of approximation.

a) $m = E/c^2$ ✓
$= \frac{1}{9\times10^{16}} = 1.1 \times 10^{-17}\,\mathrm{kg}$ ✓
[2]

b) This is a very simple model which is for estimation purposes and should not be taken as any more than that.
Distance light could travel $= ct$ ✓
which means that the length of a photon may be estimated as
$= 3 \times 10^8 \times 10^{-9} = 30\,\mathrm{cm}$ ✓

$$\text{Number of wavelengths} = \frac{0.3\,\mathrm{m}}{600\,\mathrm{nm}} = \frac{3 \times 10^{-1}}{600 \times 10^{-9}} = 5 \times 10^5$$ ✓

[3]

c) Maximum power when load is also $1\,\mu\Omega$ ✓
(Maximum power transferred to external load is when the load is equal to the internal resistance)

So current is $1\,\mathrm{MA}$, leading to an output of $1\,\mathrm{MW}$. Any sensible calculation or assertion. ✓
Any one of several problems:
$1\,\mathrm{MW}$ of power is also dissipated in the source, which may well explode;
any contact resistance will probably dominate;
the circuit will need to be made of massive conductors, etc.
Any one sensible item named ✓
and well explained. ✓
[4]

9 marks

Qu 2.

a) (i) KE $= \frac{1}{2}mv^2$ ✓

$= \frac{1}{2} \times 1000 \times 30^2 = 450\,\text{kJ}$ ✓

[2]

(ii) As KE $\propto v^2$, new KE is $\frac{1}{4}$ of initial ✓

So that $\frac{3}{4}$ is lost. ✓

[2]

b) (i) $T \propto v$ ✓

[1]

(ii) thinking time is constant / independent of the speed of the car owtte. ✓

[1]

c) (i) Two obvious methods follow; others are possible: credit correspondingly.

Either numerical check ✓ with ratio approximately constant ✓

OR graphically ✓ convincing straight line through origin, with only a little scatter. ✓

Table 1: Table of v^2/B calculated.
(note: easy units in table chosen for this)

v^2	B	v^2/B
400	6	66.7
900	14	64.3
1600	24	66.7
2500	38	65.8
3600	55	65.5
4900	75	65.3

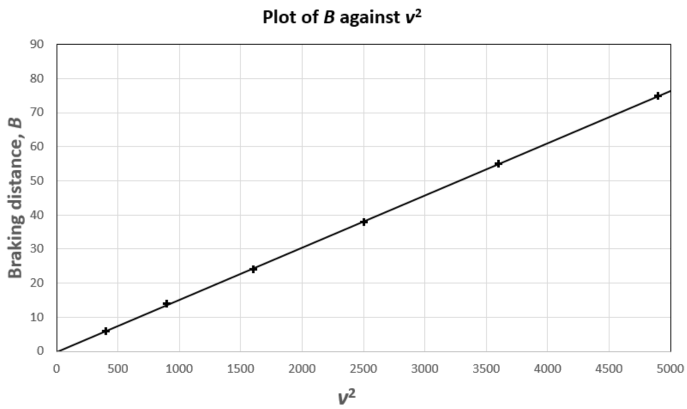


Figure 1

In either case, draw conclusion that hypothesis is reasonable. ✓

[3]

(ii) **Either** consider work done against friction by a fixed force equal to the KE lost

$\frac{1}{2}mv^2 = B \times s$

OR constant deceleration / constant retarding force, so can use **suvat**

with $B \propto v^2$ as a special case of $v^2 = u^2 + 2as$ ✓

[1]

(iii) With $v^2 = 0$, deceleration $= \dfrac{u^2}{2s}$ ✓

$= (80\,\text{km/h})^2/[2 \times 38\,\text{m}]$

$= (80000)^2/[2 \times (3600)^2 \times 38]$ <u>unit conversion</u> ✓

$= 6.5\,\text{m}\,\text{s}^{-2}$ ✓

(The calculation is the same with the work done approach) [3]

(iv) $\mu = \dfrac{ma}{mg} = a/g$ ✓

$= 6.5/9.81 = 0.663$ **or allow** $6.5/10 = 0.65$ ✓

[2]

(v) $\mu = 1 \implies a = g$ ✓

so $B = v^2/2a = 96000^2/[2 \times (3600)^2 \times 9.81]$

$= 36.2 = 36\,\text{m}$ ✓

[2]

17 marks

Qu 3.

a) Diagrams such as those below ✓✓

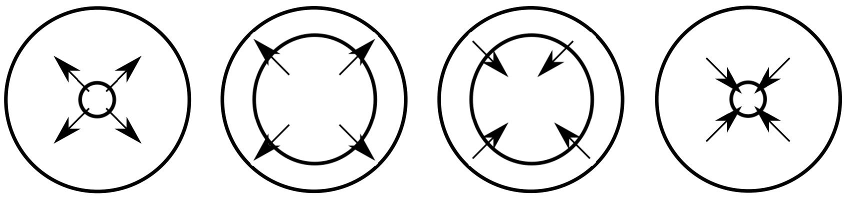


Figure 2

[2]

b) Energy distributed over a widening wavefront; therefore amplitude [not displacement] reduces as ripple spreads. ✓

[1]

c) Wavefronts spreading out from the object are caused to converge on the image. ✓
As object and image distances are equal in both instances, this occurs when these are each equal to $2f$, so the focal length of the mirror is half the radius of curvature. ✓

[2]

d) Sketch occupying half a page (no postage stamps) ✓
Added ray ✓

[2]

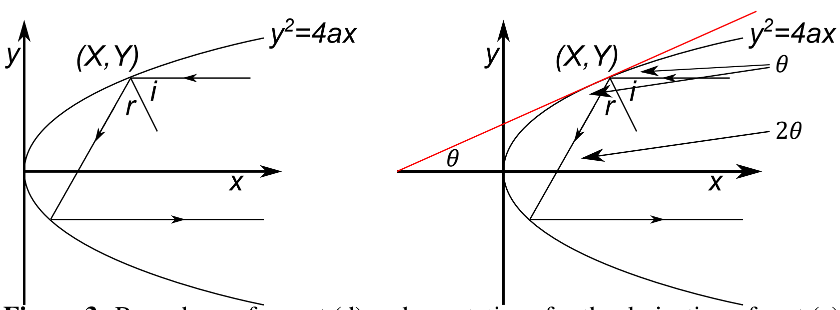


Figure 3: Rays drawn for part (d) and annotations for the derivation of part (e).

e) Differentiate: $2y\mathrm{d}y = 4a\mathrm{d}x \implies$ gradient of parabola at (X, Y) is $\frac{2a}{Y}$ ✓

So $\tan\theta = \frac{2a}{Y}$ ✓

θ and 2θ shown on diagram ✓

As $i = r$, gradient of reflected ray is $\tan(2\theta) = 2(2a/Y)/(1 - 4a^2/Y^2)$

$= \frac{4aY}{Y^2 - 4a^2} = Y/(X - a)$ ✓

Equation of path of reflected ray is given by: gradient $= Y/(X - a)$ and in general the gradient of the sloping line crossing the $x-$axis is given by $Y/(X - x)$

so this means $Y/(X - a) = Y/(X - x)$ ✓

$\implies x = a$, so reflected ray(s) passes through $(a, 0)$ ✓

This is the focus as all rays parallel to the axis pass through $(a, 0)$ after reflection

[6]

13 marks

Qu 4.

a) $\times 10^{-9}$ ✓

[1]

b) $0.2 \leftrightarrow 0.3\,\mathrm{nm}$, but allow wide margin of estimation ✓

[1]

c) Such structures are likely to be on a scale conveniently measured in nm. ✓

[1]

d) $\frac{I}{3}$ ✓

by symmetry - the network is the same if rotated by 120° ✓

[2]

e) $\frac{I}{3}$ ✓

[1]

f) $\frac{2I}{3}$ ✓

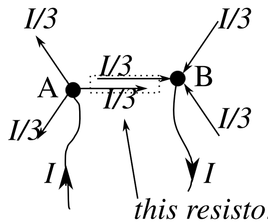
[1]

g) $\frac{I}{3}$ ✓

[1]

h) Diagram with R and R' in parallel ✓

[1]



this resistor will have $\frac{2}{3}I$ through it, leaving I/3 through the rest of the circuit. So the rest of the circuit must have twice the resistance of this resistor.

i) As current is inversely proportional to resistance $R' = 2R$, (or use $\frac{2}{3}I \times R = \frac{I}{3} \times R'$) ✓

[1]

j) Parallel addition of R and R' leads to $\frac{1}{R} + \frac{1}{2R} \rightarrow \frac{3}{2R}$, which gives $\frac{2}{3}R$ ✓

[1]

This is one approach with a mark breakdown. Students may not quite follow this train of thought and should be given credit for reaching appropriate stages.

The **superposition** argument is to consider applying two potential arrangements to the circuit, one after the other, determine currents of interest, and then apply the potentials at the same time, but with a common point which would be at the same potential for each (in this case with a common zero at ∞). Between **A** and **B**, we have ΔV which is equal to $2V$; $+V$ and $-V$ at **A** and **B** respectively. The current I entering at **A** is equal to the current leaving at **B**. We apply superposition of currents in the single bond **AB** (each current is $\frac{1}{3}I$ in the same direction), with its resistance R and superposed currents $\frac{2}{3}I$. The resistance between **A** and **B** via every route, R_{AB}, is $\frac{\Delta V}{I}$. Now the potential across R is equal to $2V$, and also equal to $\frac{2}{3}I \times R$, so that $R_{\mathrm{AB}} = \frac{2V}{I} = \frac{2}{3}R$.

11 marks

END OF SOLUTIONS