British Physics Olympiad

BPhO Physics Challenge - Mark Scheme

September/October 2020

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) Approximations:

$m \sim 70\,\text{kg}$ (between 40 and 100 kg) ✓

diameter $\sim \frac{1}{10}\,\text{mm} = 10^{-4}\,\text{m}$ $\quad (\frac{1}{50}\,\text{mm} < d < \frac{1}{5}\,\text{mm})$ ✓

So $\sigma = \frac{mg}{A} = \frac{70 \times 10}{10^{-8}}$ ✓

$= 7 \times 10^{10}\,\text{Pa}$ ✓

[4]

b) Approximations:

size of microprocessor chip (not the plastic) $\sim$ few mm $\times$ few mm ✓

$100\,\text{THz} \rightarrow$ travel time $\sim 10^{-14}\,\text{s}$ ✓

at a speed $\sim\ c = 3 \times 10^8\,\text{m}\,\text{s}^{-1}$ ✓

Max distance information could travel $= ct = 3 \times 10^8 \times 10^{-14}$

$= 3\,\mu\text{m}$ ✓

A very small chip

[4]

c) Approximations:

$r \sim 10^{-15}\,\text{m}$ (allow 10^{-14} to 10^{-16} m) ✓

so $V \sim 10^{-45}\,\text{m}^3$

Mass of Avogadro's number of hydrogen atoms (one mole) $= 0.001\,\text{kg}$ ✓

mass of atom $\approx \frac{1}{6 \times 10^{23}}\,\text{g} = 1.7 \times 10^{-27}\,\text{kg}$ ✓

$\rightarrow \rho \approx 10^{18}\,\text{kg}\,\text{m}^{-3}$ ✓

[4]

12 marks

Qu 2.

a) Conserves kinetic energy (as well as momentum) ✓

b) Stated conditions give mv and $\frac{1}{2}mv^2$ the same at start and finish, so comply with requirement for an elastic collision.

$$\text{Mom cons.} \qquad mu = mv_1 + mv_2 \qquad \rightarrow \qquad u = v_1 + v_2 \qquad (1)$$

$$\text{KE cons.} \qquad \frac{1}{2}mu^2 = \frac{1}{2}mv_1^2 + \frac{1}{2}mv_2^2 \qquad \rightarrow \qquad u^2 = v_1^2 + v_2^2 \qquad (2)$$

$$\text{From equ. } 1: \qquad u^2 = v_1^2 + v_2^2 + 2v_1v_2$$

$$\text{equatingwith } u^2 \text{ from } 2: \qquad v_1v_2 = 0$$

$$\text{so that either} \qquad v_1 = 0 \text{ and } v_2 = 0, \text{ and } u = 0 \text{ from equ. } 1, \text{ so nothing moves}$$

$$\text{or} \qquad v_2 = 0 \text{ and } v_1 = u, \text{ so no interaction}$$

$$\text{or} \qquad v_1 = 0 \text{ and } v_2 = u, \text{ the required result}$$

Equs. (1) and (2) ✓ Solving to obtain $v_1v_2 = 0$ ✓

c) Each successive ball behaves like this, so end ball jumps off and all others come to/stay at rest. Process repeats in the reverse direction continually owtte ✓
The balls may appear to be in contact, and not individual masses, but they are weakly resting aginst each other and on the atomic scale there is much non-contact space between large areas of the faces.

[4]

d) As masses of protons and neutrons are almost the same, ✓
and we assume collisions are elastic ✓
neutrons eject protons facilitating detection.

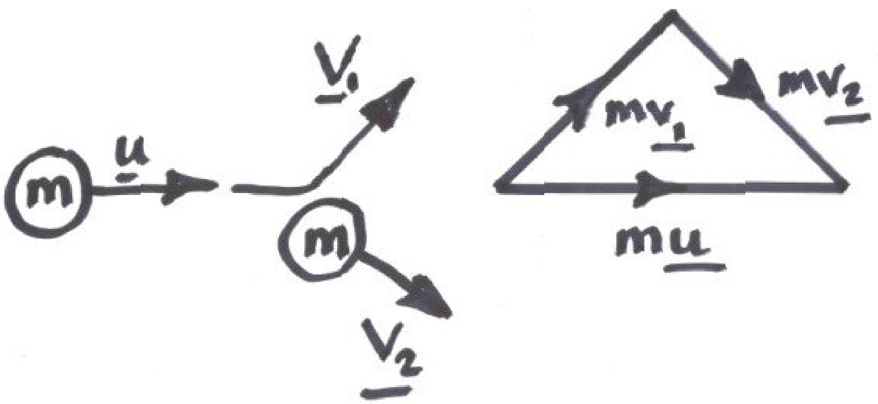

Figure 1

e) Left Hand diagram ✓

f) Right Hand diagram - conservation of momentum ✓
Using conservation of kinetic energy (elastic collision), $\frac{1}{2}mu^2 = \frac{1}{2}mv_1^2 + \frac{1}{2}mv_2^2$
This simplifies to $u^2 = v_1^2 + v_2^2$ ✓
so when applied to the momentum triangle $\vec{v}_1$ and $\vec{v}_2$ are perpendicular (by Pythagoras) ✓

10 marks

Qu 3.

a) Diagram below ✓

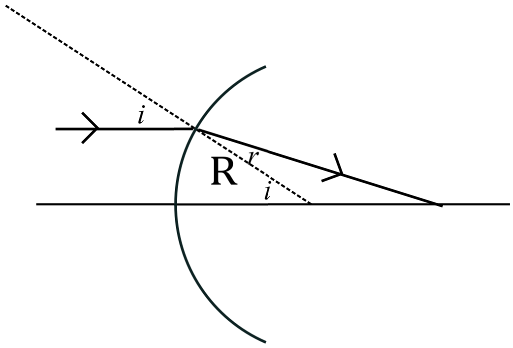

Figure 2

b) $\sin(\theta_c) = \dfrac{1}{2.0}$. So $\theta_c = 30°$ ✓

c) For small angle, $[1.0 \sin(i) = 2.0 \sin(r)] \implies r = i/n = i/2.0$ ✓

d) Diagram to show the ray meeting the surface at radius R as shown.
As angle at centre is i (corresponding angles) $\implies$ angle at RH end is also $i/2$ ✓
so triangle is isosceles. ✓
Therefore ray meets axis a distance from the centre ≈ equal to the radius ✓

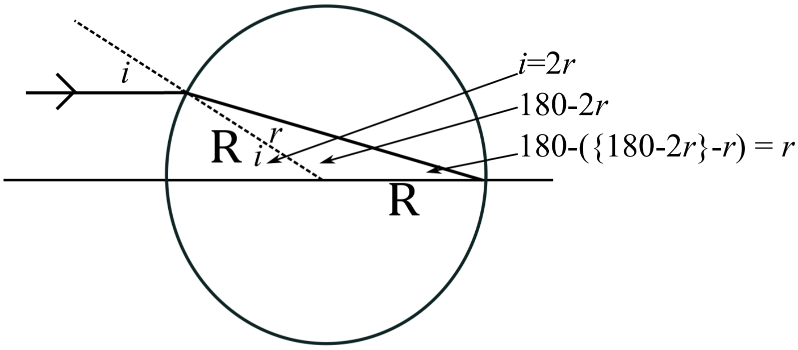

Figure 3

[6]

e) Common glasses have a refractive index somewhat less than $n = 2.0$, so making the focus just outside the sphere. ✓
The paper strip is placed the a suitable distance away from the glass.
So the Sun burns the paper, recording the strength of sunlight on the different parts of the strip as the day progresses. owtte. ✓

f) Near the Arctic Circle or at a high latitude (not at the poles - no ice) where the Sun may be above the horizon for 24 hours. ✓
(i) The Sun may be behind the right hand sphere (i.e. to the left), or (ii) the recording strip is in the horizontal plane. ✓

10 marks

Qu 4.

a) Randomness means as much charge is transfered in any given direction as in the opposite direction, so no *overall* current. ✓

b) Mass of electron is $\sim \dfrac{1}{30 \times 2000}$ that of a gas molecule. ✓

KE of each must be the same at same temperature. ✓

So velocity is $500 \times \sqrt{60\,000}$

$= 1 \times 10^5\,\mathrm{m\,s^{-1}}$ ✓

c) $v_\mathrm{d} = \dfrac{I}{nAe} = \dfrac{1}{10^{29} \times 10^{-6} \times 1.6 \times 10^{-19}} = 6.3 \times 10^{-5}\,\mathrm{m\,s^{-1}}$ ignore any $(-)$ sign. ✓

d) Many orders of magnitude slower than the thermal velocity, or other sensible comment ✓

e) Electrons throughout the circuit all start to drift almost simultaneously (establishment of $E-$field that drives them, itself propagates at $\sim$ light speed) owtte ✓

f) $E = \dfrac{V}{\ell}$ ✓

and $a = \dfrac{F}{m}$ ✓

which is $\quad a = \dfrac{eE}{m}$ ✓

So that we can write $\quad a = \dfrac{eV}{m\ell}$

[10]

g) graph (first segment) ✓

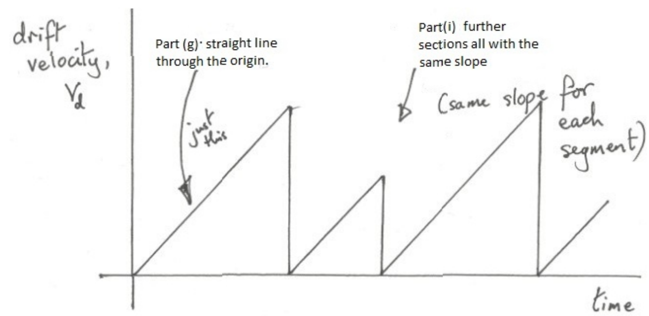

Figure 4

h) The kinetic energy associated with orderly drift has been added to the random thermal KE, raising the temperature owtte ✓

i) See diagram ✓

j) Final velocity is "at", so that $\quad a\tau = \dfrac{eV\tau}{m\ell}$ ✓

so average velocity is $\quad [v_\mathrm{d} =] \; \dfrac{eV\tau}{\mathbf{2}m\ell}$ ✓

k) $I = nv_\mathrm{d}Ae = n\dfrac{eV\tau}{2m\ell}Ae = \dfrac{nVe^2A\tau}{2m\ell}$ ✓

l) Comparing this with $R = V/I = \rho\ell/A$ ✓

$$\rho = \frac{2m}{ne^2\tau}$$ ✓

[8]

18 marks

END OF SOLUTIONS