

## 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  $\pm 1$  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  $\sim \frac{1}{10} \text{ mm} = 10^{-4} \text{ m}$       ( $\frac{1}{50} \text{ mm} < d < \frac{1}{5} \text{ mm}$ )      ✓  
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 THz  $\rightarrow$  travel time  $\sim 10^{-14} \text{ s}$       ✓  
at a speed  $\sim c = 3 \times 10^8 \text{ m s}^{-1}$       ✓  
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  $10^{-16} \text{ m}$ )      ✓  
so  $V \sim 10^{-45} \text{ m}^3$       ✓  
Mass of Avogadro's number of hydrogen atoms (one mole) = 0.001 kg      ✓  
mass of atom  $\approx \frac{1}{6 \times 10^{23}} \text{ g} = 1.7 \times 10^{-27} \text{ kg}$       ✓  
 $\rightarrow \rho \approx 10^{18} \text{ kg m}^{-3}$       ✓  
[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.

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

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

From equ. 1 :  $u^2 = v_1^2 + v_2^2 + 2v_1v_2$

equating with  $u^2$  from 2 :  $v_1v_2 = 0$

so that either  $v_1 = 0$  and  $v_2 = u$ , and  $u = 0$  from equ. 1, so nothing moves

or  $v_2 = 0$  and  $v_1 = u$ , so no interaction

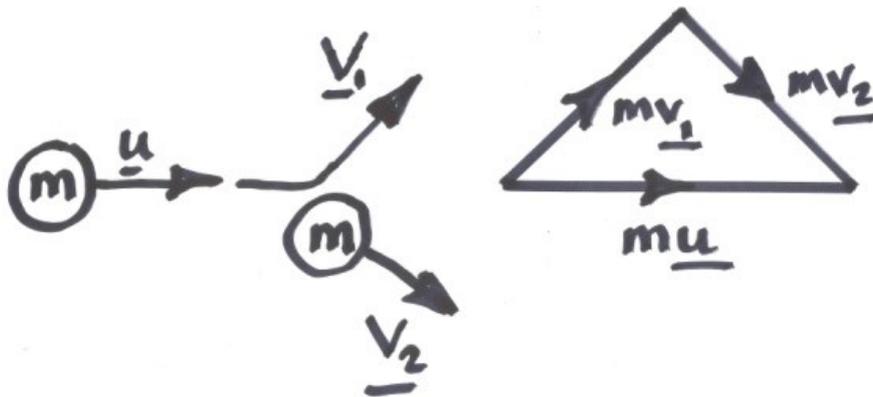
or  $v_1 = 0$  and  $v_2 = u$ , the required result

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 against 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 4.

- a) Randomness means as much charge is transferred in any given direction as in the opposite direction, so no *overall* current. ✓
- b) Mass of electron is  $\sim \frac{1}{30 \times 2000}$  that of a gas molecule. ✓  
 KE of each must be the same at same temperature. ✓  
 So velocity is  $500 \times \sqrt{60\,000}$  ✓  
 $= 1 \times 10^5 \text{ m s}^{-1}$  ✓
- c)  $v_d = \frac{I}{nAe} = \frac{1}{10^{29} \times 10^{-6} \times 1.6 \times 10^{-19}} = 6.3 \times 10^{-5} \text{ m s}^{-1}$  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)  $E = \frac{V}{\ell}$  ✓  
 and  $a = \frac{F}{m}$  ✓  
 which is  $a = \frac{eE}{m}$  ✓  
 So that we can write  $a = \frac{eV}{m\ell}$  ✓
- g) graph (first segment) ✓

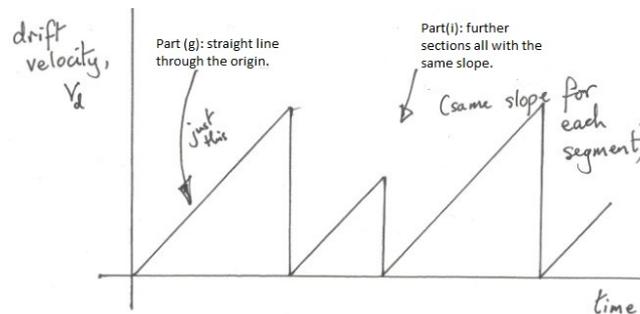


Figure 4

- 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  $a\tau = \frac{eV\tau}{m\ell}$  ✓  
 so average velocity is  $[v_d =] \frac{eV\tau}{2m\ell}$  ✓
- k)  $I = nv_d Ae = n \frac{eV\tau}{2m\ell} Ae = \frac{nVe^2 A\tau}{2m\ell}$  ✓
- l) Comparing this with  $R = V/I = \rho\ell/A$  ✓  
 $\rho = \frac{2m}{ne^2\tau}$  ✓

[10]

[8]

18 marks

END OF SOLUTIONS