# BRITISH PHYSICS OLYMPIAD 2015-16

# A2 Challenge Sept/Oct 2015

# SOLUTIONS

**Question 1**

a.

i) Suitable diagram ☑

ii) Momentum calculation; $1 \times 0.2 + 2 \times (-0.2) = 0$ i.e. total zero. *At rest* ☑

iii) At a point dividing the distance between the ships in the ratio 1:2 (closer to 2 tonne mass) ☑ Zero ☑

iv) Before KE = $\frac{1}{2}m_1 u_1^2 + \frac{1}{2}m_2 u_2^2 = \frac{1}{2}(1000 \times 0.2^2 + 2000 \times 0.1^2) = 30$ J ☑ ;

After - zero ☑

v) Suitable diagram ☑ , Momentum calculation, total 0.1 m s$^{-1}$ to the right ☑; position of c of m as before ☑; 45 J before and 15 J after ☑

vi) Kinetic energies may differ according to frame of reference, but the loss remains the same ☑

(As a de-brief point, it is instructive to demonstrate that the energy change, $\Delta E = \frac{1}{2}(m_1 + m_2)(u_1 - u_2)^2$ is unaltered by a change to a frame of reference moving at speeds, which simply alters both $u_1$ and $u_2$ by the same amount, $(u_1 - u_2) \rightarrow ((u_1 + \Delta u) - (u_2 + \Delta u))$leaving the term $(u_1 - u_2)$ unaltered.)

b.

i) Momentum calculation to show appropriate velocities ☑

Initial velocity, $u$. Final velocities $v_1, v_2$. Identical masses.

| | | |
|---|---|---|
| Mom cons. | $v_1 + v_2 = u$ | (cancel through the *m*) |
| KE cons. | $v_1^2 + v_2^2 = u^2$ | (cancel through by ½ *m*) |
| Algebra: | $(u - v_1)(u + v_{1)} = v_2^2$ | |
| And also | $(u - v_1) = v_2$ | from the initial relation |

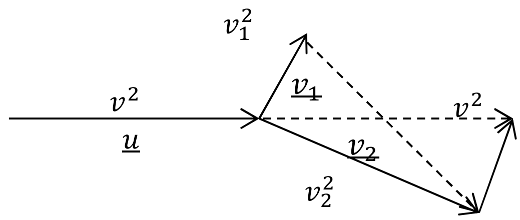
If $v_2 \neq 0$ then can divide the two equations, to get $(u + v_1) = v_2$.
Now add $(u + v_1) = v_2$ and $(u - v_1) = v_2$ to obtain $u = v_2$, so that $v_1 = 0$

Note that if $v_2 = 0$ then $v_1 = u$ and momentum and KE are both conserved, but the particles do not actually collide.

There are several other algebraic routes, including direct substitution for $u$ say, giving $v_1 . v_2 = 0$. So either $v_1 = 0$ or $v_2 = 0$.

ii) Neutron comes to rest; proton ejected (as masses are virtually equal) ☑

iii)




Let initial velocity be $v$ and final velocities be $\overrightarrow{v_1}$ and $\overrightarrow{v_2}$. Vector diagram to show $m\,\overrightarrow{v_1} + m\overrightarrow{v_2} = m\,\vec{v}$ ☑ Elastic collision gives $½mv_1^2+½mv_2^2=½mv^2$ so $v_1^2+v_2^2=v^2$ implying (Pythagoras) that the momentum diagram is a right-angled triangle, proving the proposition . ☑ **owwt**

Note: the analysis given in (i) is adaptable. Write cons. of mom as $\vec{u} = \overrightarrow{v_1} + \overrightarrow{v_2}$.
Squaring, $u^2 = v_1^2 + v_2^2 + 2\overrightarrow{v_1}.\overrightarrow{v_2}$. With the KE result, $u^2 = v_1^2 + v_2^2$ clearly $2\overrightarrow{v_1}.\overrightarrow{v_2} = 0$
Thus $v_1 = 0$ (linear collision as in (i)), $v_2 = 0$ (no collision), or $\cos\theta = 0 \Rightarrow \theta = \pi/2$

iv) Traces (such as cloud chamber tracks) seen to be perpendicular, when in the plane normal to the line of sight. ☑

**[16 marks]**

**Question 2**

a.

i) Initial volume 1000 mm$^3$; final volume 1000.40 mm$^3$ ☑ Increased (trivial)

ii) Bonds between atoms stretched, so a net volume increase reasonable **owtte** ☑

iii) lateral strain= (-)0.0003; longitudinal strain= 0.001. So Poisson Ratio (-)0.3 ☑.

b.

i) Use binomial theorem or error theory ideas :
$V = lA$ so $\frac{\delta V}{V} = \frac{\delta A}{A} + \frac{\delta l}{l}$, from binomial or by differentiation.
Since $\frac{\delta V}{V} = 0$ for rubber, and since $\frac{\delta l}{l}$ increases by 2%, then $\frac{\delta A}{A}$ reduces by 2% ☑

ii) $A = w^2$ so $\frac{\delta A}{A} = 2\frac{\delta w}{w}$. Hence $\frac{\delta w}{w}$ is reduced by 1% ☑

iii) By inspection (-)0.5 ☑

**[6 marks]**

**Question 3**

a. i) Suitable *symmetrical* diagram ☑

ii) Angle-sum of triangles gives $\angle$i for incident ray as (A+D)/2 ☑ $\angle$r = A/2 ☑

$$n=\frac{\sin((A+D)/2)}{\sin(A/2)}$$ follows from Snell's Law ☑

i) For $\sin\theta \approx \theta$ this reduces to $n = \frac{(A+D)/2}{A/2}$ ☑ which re-arranges to $D = (n-1)A$ ☑

b.

i) Deviation = (n-1)A = 0.5 x 0.02 = 0.01 rad ☑

ii) $SS_1$ = distance to prism × deviation angle = 0.1 m x 0.01 = 0.001 m ☑
So $S_1S_2$ = 0.002 m. ☑

iii) Both derived from same source **owtte** ☑

iv) fringe width, $w = L\lambda / S_1S_2$ = (1.9+0.1) ☑ x $5\times10^{-7}$ / 0.002 = $5\times10^{-4}$ m ☑

**[12 marks]**

**Question 4**

a. A real source with emf 3.0 V and internal resistance 1.0 Ω is connected to a resistor of resistance 2.0 Ω.

i) $I = V/R_{circuit}$ = 3/3 = 1 A ☑ ; $V = IR_{2\Omega}$ = 1 x 2 = 2 V ☑

ii) Net emf = 3 V – 3 V = 0, thus zero current also ☑

iii) By symmetry, or folding over the circuit to superimpose the cells and 1 Ω resistors, the system has E = 3 V, r = 0.5 Ω connected to 2.5 Ω load. I = V/R = 3 V/3 Ω = 1 A ☑

iv) Now for whole circuit, I= V/R = 6 V/2 Ω = 3 A. ☑ Consider either cell: $V_{XY}$ = zero ☑

b. We will now explore the effect of internal resistance in some practical situations.

i) Current through person is V/R = 5000 V / 10 001 000 ≈ 0.5 mA (or potential divider idea, pd across person ≈ 5 V leads to I = 0.5 mA) ☑ Therefore harmless (trivial)

ii)

1) Vit = 12 V x 1 A x (60x3600) s = 2.59 MJ ☑

2) I = V/R = 12/ 0.01 = 1200 A ☑ ; P = $V^2/R$ = 144/0.01 = 14.4 kW ☑

3) Heat inside the battery ☑ eventually boils electrolyte with explosion risk or other sensible comment.

**[11 marks]**

**Question 5**

This question looks at some practical consequences of the evaporation of liquids.

Placing a liquid in a vacuum (e.g. a leak from a space vehicle) forces it to evaporate and can lead to rapid cooling.

a. mc ΔT = 0.01mL hence ΔT = 0.01L/c= .01x $2.26\times10^6$ / 4200 = 5.4°C ☑, new temperature (assuming no other losses) is 4.6°C ☑

b. All factors lead to rapid evaporation and thus heat loss and sensation of cold **owtte** ☑

c. Draught enhances evaporation rate. Thus faster cooling **owtte** ☑

d. More volatile liquids evaporate even faster ☑

**[5 marks]**