British Physics Olympiad

BPhO Physics Challenge - Mark Scheme

September/October 2022

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) (i) $F = pA = 10^5 \times 10^{-2} = 1\,\text{kN}$ ✓

(ii) The factor change is large, but the difference in value is minute so the *differential* pressure is virtually unaltered; ✓
so therefore the stress (and the likelihood of implosion) is effectively unchanged. ✓

(3 marks)

b) Suppose the gas in the balloon has a fraction, say $\frac{1}{16}$ for H_2 or $\frac{1}{8}$ for He of the density of air.
A person has a mass of $70\,\text{kg}$, so the upthrust of the balloon would need to be $70\,\text{kg}$. ✓
The weight of cold air displaced = the weight supported (person + gas).
Hence $W_{\text{air}} = mg + W_{\text{gas}}$ ✓
$W = \rho V g$ and so, $\rho_{\text{air}} V = m + \rho_{\text{gas}} V$
Hence, $V = \dfrac{m}{\rho_{\text{air}} - \rho_{\text{gas}}}$
As air has density $\approx 1.2 \approx 1\,\text{kg}\,\text{m}^{-3}$ and $\rho_{\text{gas}} \approx \frac{1}{10}\rho_{\text{air}}$, this implies a volume of $\approx 70\,\text{m}^3$, $(V = \frac{4}{3}\pi R^3)$ and therefore a radius of $\approx 2.2\,\text{m}$. Anything between 2 and $3\,\text{m}$ is reasonable. ✓
Sensible values accepted if beyond this range.. (3 marks)

c) Suppose that the monolayer is about two atoms thick, so approx $0.5\,\text{nm}$ ✓

The tyre is approx $0.7\,\text{m}$ in diameter, circumference is approx $0.7\pi\,\text{m}$
Annular cross section to wear away is therefore $0.7\pi(8 - 1.6) \times 10^{-3}\,\text{m}^2$ ✓
So expected distance is $0.7\pi(8 - 1.6) \times 10^{-3}\,\text{m}^2 / 0.5 \times 10^{-9}\,\text{m} = 28\,000\,\text{km}$ ✓
Allow any reasonable estimates and methods
(Answer is about right for front tyres: rears tend to do rather better as the stresses of FWD power application and cornering do not apply)

(3 marks)

[Total 9 marks]

Qu 2.

a) (i) $2\,\mathrm{A}$ ✓

(ii) $4I$ as $I \propto (\text{amplitude})^2$ ✓

(iii) zero (iv) $2I$ need both parts to score ✓

(v) As two sources each give I then $2I$ conserves energy owtte ✓

(4 marks)

b) (i) $4A$ at anti-nodes , $2A$ at nodes ; $16I$ at the anti-nodes, $4I$ at the nodes. ✓
average given by $(3A)^2 + (1A)^2 = 9A^2 + A^2 = 10I$ which is the average of $16I$ and $4I$ as before. ✓✓

(ii) amplitudes at antinode $A_1 + A_2$ and node $A_1 - A_2$;
$I_{\text{antinode}} = k(A_1 + A_2)^2$ and $I_{\text{node}} = k(A_1 - A_2)^2$ ✓
Average of last two is $k\frac{1}{2}(A_1^2 + A_2^2 + \cancel{2A_1A_2} + A_1^2 + A_2^2 - \cancel{2A_1A_2}) = kA_1^2 + kA_2^2$, which is the sum of the individual intensities from the two slits. ✓

(5 marks)

[Total 9 marks]

Qu 3.

a) (i) (T is the same throughout; on left pulley, $2T = mg$); $\frac{1}{2}mg$

(ii) (If left pulley raised by h then $2h$ of cord 'removed'); $2h$ } ✓

(iii) $\frac{1}{2}mg \times 2h = mgh$ ✓

(iv) The same; mgh, so 100% ✓

(3 marks)

b) (i) $\dfrac{mg}{6}$

(ii) $6h$ } ✓

(iii) $\dfrac{mg}{6} \times 6h = mgh$ ✓

(iv) The same; mgh, so $\eta = 100\%$ ✓

(3 marks)

c) (i) $T = \left(m + \dfrac{m}{k}\right)\dfrac{g}{6} = \dfrac{mg}{6}\left(1 + \dfrac{1}{k}\right)$ ✓

(ii) $6h$

(iii) $\text{WD} = mgh\left(1 + \dfrac{1}{k}\right)$ } ✓

(iv) Useful work $= mgh$, so efficiency is now $\eta = \dfrac{mgh}{mgh\left(1 + \frac{1}{k}\right)} = \dfrac{k}{1+k}$ ✓

(3 marks)

d) (i) $2\pi R$

(ii) $2\pi r$ $\Big\}$ ✓

(iii) $2\pi(\frac{R-r}{2})$ (halved as the length difference is removed from the two vertical strings) therefore load rises by $\pi(R-r)$ ✓

(iv) m rises by $\pi(R-r)$, so increasing GPE by $mg\pi(R-r)$; ✓
while T moves a distance $2\pi R$, so, assuming 100% efficiency as before, $2\pi RT = mg\pi(R-r)$ so $T = \frac{1}{2}mg(1-\frac{r}{R})$ ✓
(The result may also be obtained by considering moments for the upper pulley)

(v) Lifting very heavy loads requires that the $\left(1-\frac{r}{R}\right)$ term becomes very small; ✓
as this term $\to 0$, $r \to R$, so the displacement of the load becomes vanishingly small. ✓

(6 marks)

[Total 15 marks]

(Discussion points: how is it ensured that the cords do not slip on the pulleys? Examine the illustration below: the usual form of this mechanism has depressions in the pulleys to engage with the chain shown in **Figure 1**.)

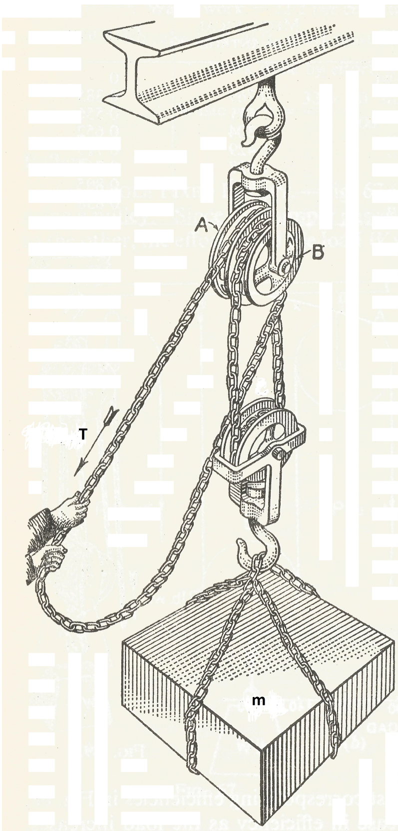

Figure 1: Two light pulleys and a light cord.
credit: General Physics by W L Whitely, University Tutorial Press, 1965

(It is dangerous to lift heavy objects using a simple pulley as letting go of the cord will cause the load to fall in an uncontrolled manner. Some systems are designed to be considerably less than 50% efficient so that the friction forces exceed the forces doing work and storing energy. So, when the system is released, friction is sufficient to prevent run-away and lowering the load can be achieved in a controlled manner.)

Qu 4.

a) (i) Desiccated, combustible tree + HOT incandescent bulb
= fire risk or other sensible comment ✓
(Worse for the Victorians: they used real candles!)

(ii) $20 \times 12\,\text{V}$ in series adds to $240\,\text{V}$, so OK. ✓

(iii) Treat as a 3 : 1 potential divider, or $15 \times 12\,\text{V} = 180\,\text{V}$ ✓

(3 marks)

b) (i) All bulbs extinguish ✓ (as no complete circuit)

(ii) **WX** : $0\,\text{V}$; **WY** : $0\,\text{V}$; ✓
so wherever the contact is made the same result occurs so not revealing the faulty bulb. ✓

(iii) **WX** : $240\,\text{V}$; **WY** : $0\,\text{V}$; ✓
YES; ✓ as the change of voltage happens across the faulty bulb. ✓

(iv) $0\,\text{V}$; ✓
(but BEWARE! All the section is at $240\,\text{V}$ wrt **W**, so no potential DIFFERENCE)

(v) Electric shock if both the bulb contacts are touched; ✓
as one is at $0\,\text{V}$ and the other at $240\,\text{V}$ wrt **W**. ✓

(9 marks)

(Discussion points:

i. Earthing either **W** or **Z** (but obviously not both) will lead to other potential ways for the hapless householder to accidentally electrocute themselves. This may lead to why the switches in domestic installations break the Live not the Neutral side.

ii. The only sure way to be safe is a double pole switch that completely isolates the system from the supply, which is what the main switch and some other special ones found in domestic situations do.
Moral of all this: while it is safe to use low voltages as we do in the lab, leave everything else well alone!)

c) (i) ***Bulb 6*** extinguishes but the rest remain alight / become a little brighter. ✓

(ii) Across failed bulb $0\,\text{V}$; remainder $240/19 = 12.6\,\text{V}$ ✓

(iii) Remaining bulbs brighter (may have been seen in c(i)). ✓
Therefore run hot and more susceptible to premature failure. ✓

(iv) As more and more bulbs fail, the rest get hotter and hotter, so failing at an increasing rate; the last few get very hot and could ignite the tree! Or similar sensible explanation leading to a progressive failure scenario. ✓

(5 marks)

[Total 17 marks]

(Discussion point: This sort of progressive collapse can happen in all sorts of situations and is something of which engineers are rightly wary. Historically famous bridge collapses and failure of high rise buildings have followed similar progressive failure, which students might like to research.)

END OF SOLUTIONS