British Physics Olympiad

BPhO Physics Challenge - Mark Scheme

September/October 2023

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) Estimate volume 0.25 litres so $m = 0.25\,\mathrm{kg}$; $c = 4180\,\mathrm{J\,kg\,K^{-1}}$, $\Delta T = 90\,\mathrm{K}$ ✓
So $E = mc\Delta T = 0.25 \times 4180 \times 90\,\mathrm{J} = 94\,050\,\mathrm{J}$ ✓
Cost is $94\,050 \times \frac{45}{3\,600\,000} = 1.18\,\text{pence} \approx 1\,\mathrm{p}$ ✓

(3 marks)

b) On any day $5 \times 3 \times 10^6$ people are infected,
so $5 \times 3 \times 10^6 \times 10^{10} = 1.5 \times 10^{17}$ particles in victims ✓
Each particle is $\approx 10^{-21}\,\mathrm{m^3}$, so volume is $1.5 \times 10^{-4}\,\mathrm{m^3} \approx 10^{-4}\,\mathrm{m^3}$ ✓

(2 marks)

c) (i) Shape, shoulder, suggested forward conduction voltage value. ✓

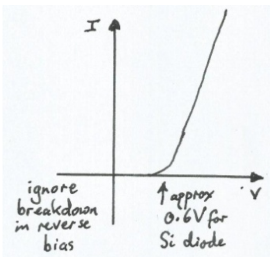
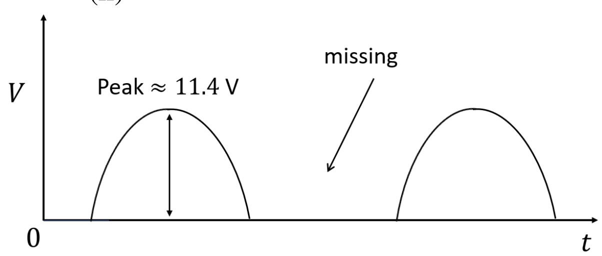
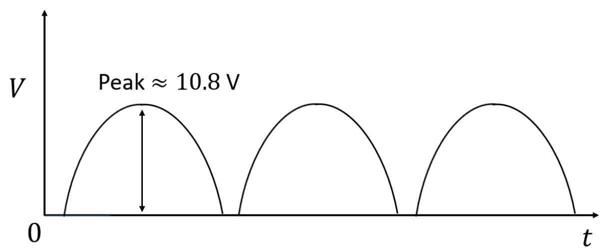


Figure 1: Diode characteristic (an $I - V$ graph)

(ii)



(a) Half-wave rectification.



(b) Full-wave rectification.

Figure 2

General shapes - a mark for each ✓✓
Note small gaps on the X-axis where diode is 'switched off' ✓
and reductions to $V_{\max}$ consistent with the diode graph. (both correct) ✓
(Adjust values if a different switch-on voltage is used (e.g. $0.3\,\text{V}$ for a Ge diode))

(5 marks)
[Total 10 marks]

Qu 2.

a) (i) Correct field direction (RH screw) (alternative perspectives allowed) ✓

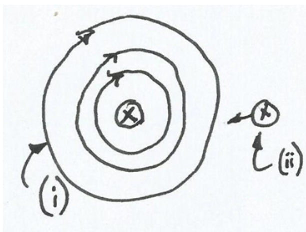


Figure 3: magnetic field pattern.

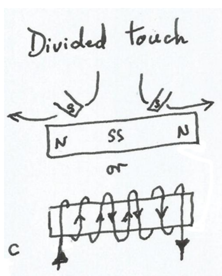
(ii) Identical second field. Either Fleming used (no explanation required) or the field lines between the currents partially cancel and so field strength reduced and/or field lines join to form oval/figure of eight, and **the wires/currents are pulled together**. ✓
This visual field line approach with parallel lines repelling, and tension in lines "shortening" them can be seen in bar magnets attracting and repelling.

(iii) Parallel currents attract; anti-parallel currents repel. ✓

(iv) As the value of an alternating current passes through zero twice per cycle, for a $50\,\text{Hz}$ transformer, there are 100 cycles of expansion/ contraction of the transformer coils per second. ✓
One octave below middle C would be $128\,\text{Hz}$, confirming the observation. ✓

(5 marks)

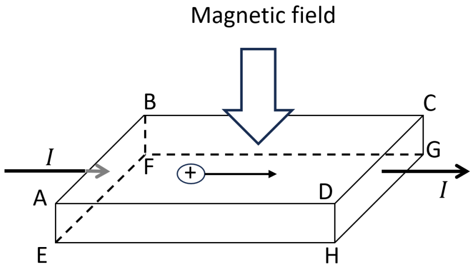
b) Either a stroking method such as divided touch **OR** a DC solenoid with suitable windings will create "consequent poles", thus:



Any valid response ✓✓
(2 marks)

c) The bar which is attracted to no other is the non magnetic material. ✓
Place the other two in a T-shaped configuration: the bar which, when placed at the mid-point of the other leads to attraction, is the magnet whilst the other is the non-magnetised magnetic material. Or similar test. ✓
(2 marks)

d) Referring to the diagram below:



(i) (Using FLHMR), towards face BCGF. ✓

(ii) BCGF +; ADHE − ✓

(iii) Still towards BCGF ; ✓
polarity reversed ✓
(note that it is conventional current which decides direction)

(iv) Check polarity of voltage between the faces mentioned above, using a voltmeter. ✓

(5 marks)
[Total 14 marks]

Qu 3.

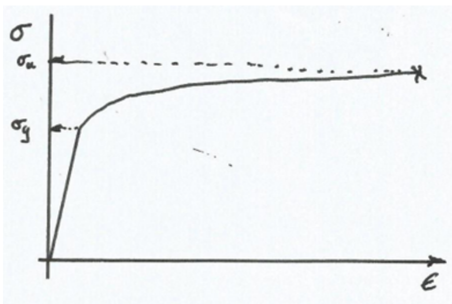
a) (i) $p = \dfrac{F}{A} = \dfrac{mg}{a^2} = \dfrac{\rho g a^3}{a^2} = \rho g a$ ✓

(ii) Any sensible idea e.g. preparation will leave scratch marks ..... even atomically flat surface has atom-sized bumps (see how field-ion, atomic force and scanning-tunnelling microscopes form images) ✓

(iii) Area of contact less as roughness reduces the value from the "whole area" estimate ✓

(3 marks)

b)



(i)
i. shape ✓
ii. stresses marked ✓
iii. Elastic $0 < \sigma < \sigma_y$ ✓
iv. Plastic $\sigma_y < \sigma < \sigma_u$ ✓

(4 marks)

c) (i) Vanishingly small, much less than the surface area, etc.,so stress very high owtte ✓

(ii) Plastic deformation until $\sigma_y = \sigma_u$ when system comes to equilibrium ✓

From this point on, we simplify the argument by ignoring the differences in the values for the stresses in tension, compression and shear.

(iii) Using the principle above, $A = \dfrac{R}{\sigma_y}$ ✓

(iv) $F = \sigma_u A = \sigma_u \dfrac{R}{\sigma_y}$ ✓

so $F = \dfrac{\sigma_u}{\sigma_y} R$ i.e. $F \propto R$ ✓

(v) • The two stresses in the previous answer are a property of the materials forming the two surfaces ✓

- In equilibrium, force F, is the normal reaction corresponding to the applied force, so follows from the previous answer ✓
- The equation $F = \mu R$ does not contain the nominal area of contact, only the true value calculated from the ratio of two stresses. ✓

As an aside, notice that this model also suggests $\mu < 1$ as $\sigma_{\mathrm{y}} < \sigma_{\mathrm{u}}$

(vi) Law 3 contradicts this assertion: in any case, the function of the tread pattern is water dispersal in wet weather (racing cars use ‘slicks’ in dry weather and change tyres in the rain). owtte ✓

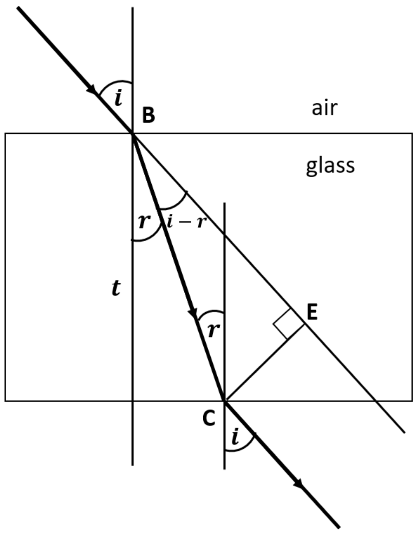
(9 marks)

[Total 16 marks]

Qu 4.

a)

CE is the displacement d



(i) Diagram ✓

(ii) Emergent ray is parallel to incident ray (displacement, sideways movement, without deviation, no change of direction) owtte ✓

(iii) By inspection,

d (i.e. **CE**) $= \dfrac{t}{\cos r} \times \sin(i - r)$ ✓

Using the identity

$\sin(i \quad r) = \sin i \cos r - \cos i \sin r$,

we have $d = t \sin i \left(1 - \dfrac{\cos i \sin r}{\sin i \cos r}\right)$ ✓

Substituting using $\cos\theta = \sqrt{1 - \sin^2\theta}$ and $\sin r = \sin i / n$, we obtain

$d = t \sin i \left(1 - \sqrt{\dfrac{(1 - \sin^2 i)}{(n^2 - \sin^2 i)}}\right)$ as required ✓✓

(6 marks)

b) (i) For small angles, $\sin\theta \approx \theta$ (θ in radians)

So, $\sin^2\theta \ll 1$ making the expression under the radical equal to $\dfrac{1}{n}$, ✓

so, $d = t \sin i \left(1 - \dfrac{1}{n}\right) = \pi t i (n - 1)/180n$ ✓

(NB conversion deg to rad for $\sin i$)

(ii) By inspection, the data produces exact proportionality, ✓

so using $d = \pi t i (n - 1)/180n$ and $i = 1^\circ$,

$0.058 = \pi \times 10 \times 1(n - 1)/180n$

whence $n = 1.50$ ✓

(4 marks)

[Total 10 marks]

END OF SOLUTIONS