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MARKSCHEME

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PHYSICS

Higher Level

Paper 3

19 pages

There are several occasions when a mark is awarded for the correct answer and another one is given for the correct reasoning *e.g.* H1(c). In general, the right answer for wrong reasons gains no credit, but the point is to allow ***[1 mark]*** for muddled or missing reasoning.

OPTION D — BIOMEDICAL PHYSICS

D1. (a) observer in sound proof room / any sensible precaution; ***[1]***
increase intensity at one frequency until audible to observer / OWTTE; ***[1]***
repeat for different frequencies **and** different observers; ***[1]***
[3 max]

(b) 1500 Hz ***[1 max]***
accept 800 → 2300 Hz;

(c) from graph from 200 → 4300 Hz; ***[1 max]***
accept 150 → 250 and 3000 → 5000 Hz
Reject answers that have the correct numbers but give two ranges and leave out the correct range.

(d) as you get older hearing decreases; ***[1]***
particularly at high frequencies; ***[1]***
[2 max]

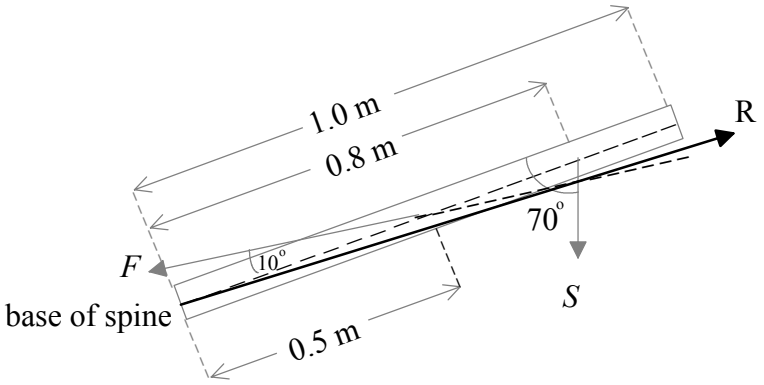
(e) from graph, hearing loss = –20 dB; ***[1]***
normal hearing at this frequency is 10^{-12} W m^{-2} seen or implied; ***[1]***
calculation (or otherwise) give 20 dB loss = 10^{-10} W m^{-2} ; ***[1]***
[3 max]

(f) no; ***[1]***
any sensible statement / argument; ***[1]***
e.g. to correct hearing loss back to zero, higher frequencies must be preferentially amplified more / OWTTE
[2 max]

D2. (a) no resultant force (in any direction); ***[1]***
no resultant torque (about any axis); ***[1]***
[2 max]

(b) force from base to spine anywhere to the right **and** up the page; ***[1]***
correctly going through the point where the other forces meet; ***[1]***
[2 max]

A*ccept forces meeting at one point it they do so within 5 mm.*



(c) use of torque = force × **perpendicular** distance; ***[1]***
to give torque = $S \sin(70) \times 0.8$ ($= 0.752\ S$); ***[1]***
[2 max]

(d) correct balance of torques; ***[1]***
$F \sin(10) \times 0.5 = S \sin(70) \times 0.8$
to give $F / S = 0.8 \sin(70) / 0.5 \sin(10) = 8.66 \approx 9$; ***[1]***
[2 max]

D3. (a) biological half life is time taken for half the amount of chemical to be removed from the body due to natural process / OWTTE; ***[1]***

physics half-life is time taken for half the nuclei to decay radioactively / OWTTE; ***[1]***

[2 max]

(b) realisation that 40 days = 2 biological half-lives ***[1]***

… and that 40 days = 5 physical half-lives; ***[1]***

so amount remaining = $(0.5)^7$ = 0.8 %; ***[1]***

[3 max]

(c) absorbed dose is the amount of energy per kg…; ***[1]***

…whereas dose equivalent takes into account the different effects that different radiations have on biological tissue; ***[1]***

mention of :– dose equivalent = quality factor × absorbed dose; ***[1]***

[3 max]

(d) *Each relevant precaution **[1]** each.*

e.g. introduce minimum required to achieve purpose / shield / monitor those working with radioisotopes / introduce non toxic chemicals *etc.*

[2 max]

OPTION E — HISTORICAL PHYSICS

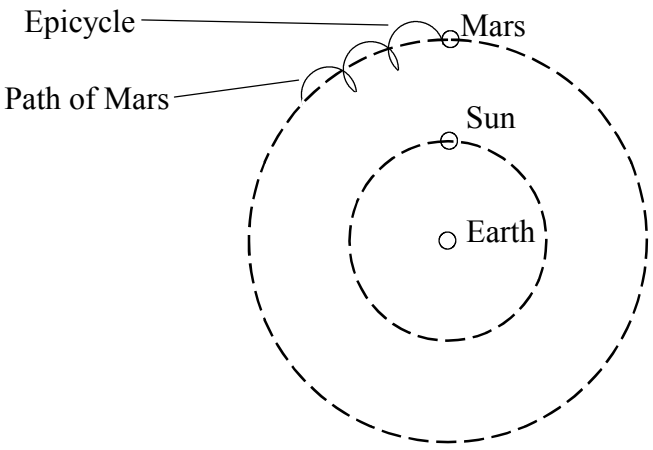
E1. (a) Aristotle: natural place of smoke is up / heavens whereas natural place of stone is on ground / OWTTE; ***[1]***
Galileo: stone falls with uniform acceleration due to gravitational force; ***[1]***
smoke rises as it is displaced by more dense air / OWTTE; ***[1]***
[3 max]

(b) Aristotle: 100 kg object would fall much faster than 10 kg object; ***[1]***
Galileo: objects would fall (nearly) together; ***[1]***
[2 max]

(c) Aristotle: forward force of motion **and** gravity; ***[1]***
Accept answers that also include friction.
Galileo: only force of gravity (and friction); ***[1]***
[2 max]

E2. (a) Venus - orbit shown around the Earth; ***[1]***
…between Sun and Earth; ***[1]***
Stars - all the same distance on 'shell' beyond Mars; ***[1]***
Reject 'beyond the Sun' without some extra detail.
[3 max]

(b) explanation involving the word 'epicycles'; ***[1]***
correctly shown on diagram; ***[1]***
[2 max]



E3. (a) Caloric / Phlogiston ***[1 max]***

(b) (i) to measure the mechanical equivalent of heat / OWTTE ***[1 max]***

(ii) temperature difference for water; ***[1]***
mass of water; ***[1]***
weight of weights; ***[1]***
distance fallen by weights; ***[1]***
[4 max]

(iii) no longer thought considered to be a fluid…; ***[1]***
…but another form of energy / OWTTE; ***[1]***
[2 max]

E4. (a) entropy ***[1 max]***

(b) the entropy of the Universe always increases / OWTTE ***[1 max]***

(c) before Boltzmann, entropy was a macroscopic property / OWTTE; ***[1]***
he related entropy to statistical concepts / OWTTE; ***[1]***
[2 max]

Award full marks to a candidate who makes relevant and appropriate observations, even if they do not include both of the above points.

E5. (a) U, U and S; ***[1]***
need all to be correct
shows that charge for the combination fit the properties of Σ^+; ***[1]***
Can get e.c.f. if their combination agrees with the charge.
shows that strangeness for the combination fit the properties of Σ^+; ***[1]***
Can get e.c.f. if their combination agrees with the strangeness.
[3 max]

(b) colour force / strong interaction; ***[1]***
due to interchange of gluons; ***[1]***
[2 max]

(c) Charm, top (truth) and bottom (beauty) ***[1 max]***
*All **three** required for mark.*

OPTION F — ASTROPHYSICS

F1. (a) Aldebaran; ***[1]***
the lower the magnitude, the brighter the star / OWTTE; ***[1]***
[2 max]

(b) apparent magnitude is the magnitude the star has as observed from the Earth whereas absolute magnitude is the magnitude the star would have if it could be place at a fixed distance from the Earth…; ***[1]***
…of 10 pc; ***[1]***
[2 max]

(c) Aldebaran; ***[1]***
since it is brighter even though it is further away. If the stars were the same distance away, it must be even brighter and hence have the smallest number for absolute magnitude; ***[1]***
[2 max]

(d) use of $p = \frac{1}{d}$ to give $d = \frac{1}{p} = \frac{1}{0.148} = 6.76$ parsecs; ***[1]***
conversion of distance into ly; ***[1]***
6.76 parsecs = 6.76 × 3.26 ly = 22.03 ly ≈ 22 ly
[2 max]

(e) expect Aldebaran's parallax angle to be smaller; ***[1]***
because it's further away; ***[1]***
[2 max]

(f) reading period from first graph = 5.4 days; ***[1]***
accept 5.2 → 5.6
using second graph to give peak absolute magnitude = –2.9; ***[1]***
accept –2.8 → –3.0
[2 max]

(g) reading peak apparent magnitude from first graph = 3.6; ***[1]***
correct attempted use of equation. *i.e.* $m = 3.6$ and $M = -2.9$;
to gives $\log\left(\frac{d}{10\text{ pc}}\right) = \frac{6.5}{5} = 1.3$; ***[1]***
correct use of antilog to get $d = 10 \times 10^{1.3} = 199.5 \approx 200$ pc; ***[1]***
Watch for e.c.f. from candidates values — allow 5 % error on values read from graph.
[3 max]

F2. (a) Y axis: Luminosity (relative to the Sun) or absolute magnitude; ***[1]***
reject 'magnitude'
X axis: (decreasing) temperature or spectral class (OBAFGKMN); ***[1]***
A*ccept just 'temperature' even if it implies they think the axis goes the other way – it is tested below.*
[2 max]

(b) (i) surface temperature of Spica higher than our Sun **since** to the left on the diagram ***[1 max]***
Do not accept answer without justification but do not allow e.c.f. from (a).

(ii) mass of Spica higher than our Sun **since** higher up on the diagram ***[1 max]***
Do not accept answer without justification.

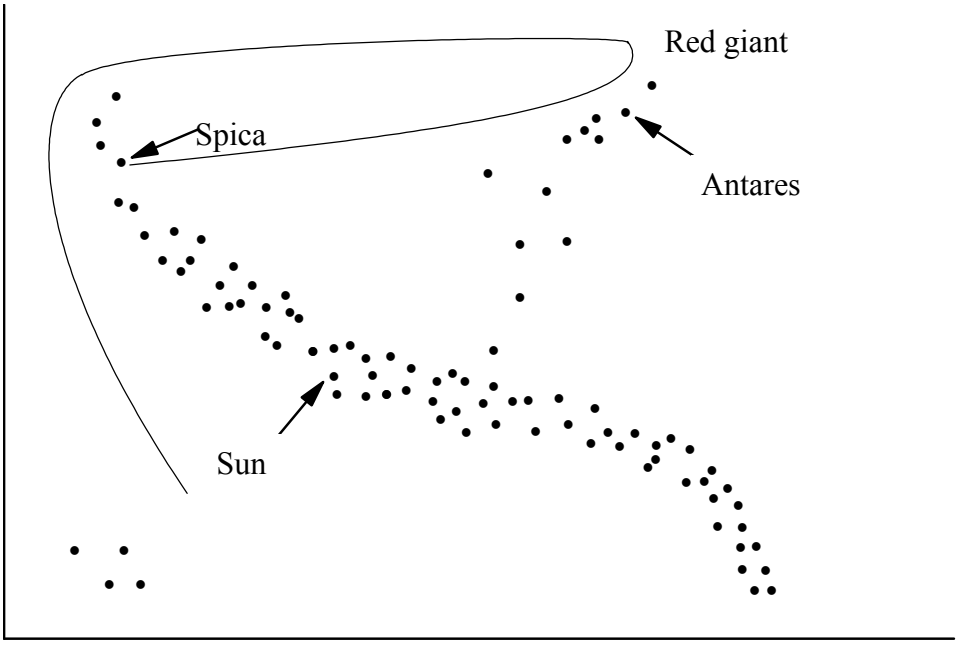
(c) peak wavelength = 500 nm; ***[1]***
accept 450 → 550 nm
so $T = \frac{2.90\times10^{-3}}{5\times10^{-7}} = 5800$ K; ***[1]***
range gives: 5300 K → 6400 K
Use of Wien law with wrong value for λ max (e.g. 300 nm) gets zero; [***2 max]***

(d) (i) dark absorption lines in otherwise continuous spectrum from the Sun / OWTTE…; ***[1]***
are characteristic of particular elements; ***[1]***

(ii) characteristic line are 'shifted' in spectrum from star; ***[1]***
amount of shift gives a measure of recession velocity / mention of 'Doppler' shift for light / OWTTE; ***[1]***
[2 max]

(e) Spica on main sequence therefore fusing hydrogen whereas…; ***[1]***
antares likely to be Red giant therefore fusing helium and/or higher elements / mention of 'shell burning' / OWTTE; ***[1]***
[2 max]

(f) initially goes to Red giant phase / OWTTE; ***[1]***
then neutron star or black hole (large mass); ***[1]***
reject white dwarf
process correctly shown on Hertzsprung-Russell diagram; ***[1]***
[3 max]



OPTION G — SPECIAL AND GENERAL RELATIVITY

G1. (a) the time as measured on a clock that is stationary in the observer's frame of reference / OWTTE ***[1 max]***

(b) therefore $\gamma = \frac{\Delta t}{\Delta t_0} = \frac{10}{6} = 1.67$ ***[1 max]***

(c) use of $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ even if the mathematics is in error; ***[1]***

correct calculation of v=0.8 c; ***[1]***

$$1-\frac{v^2}{c^2} = \frac{1}{\gamma^2}$$

$$\text{therefore } v = \sqrt{1-\frac{1}{\gamma^2}} \times c = \sqrt{1-\frac{1}{1.67^2}} \times c = 0.8\ c$$

[2 max]

(d) also 0.8 c ***[1 max]***
allow 'same as (c)' OWTTE

(e) realisation that time dilation will mean answer is less than 6 s; ***[1]***
same value of γ for Δt = 6 s **and** Δt_0 = ?; ***[1]***

gives $\Delta t_0 = \frac{6}{1.67} =$ 3.6 s; ***[1]***

[3 max]

First point does not need to be explicit, but can be used to reward a candidate that is thinking on the right lines. Correct answer gets full marks.
Given that the question is open to misinterpretation, candidates who calculate a time of 10 s should be given credit for each appropriate comment or step in the calculation up to ***[3 max]****.*

(f) neither version of time is correct / both correct / OWTTE; ***[1]***
any valid point; ***[1]***
e.g. both are correct since the observers are inertial / if two observes are moving with respect to each other, they will always disagree on the correct measurement of time / appropriate mention of twin paradox situation etc.

[2 max]

G2. (a) (i) zero (P and Q have equal and opposite momenta) ***[1 max]***

(ii) $\gamma = \dfrac{1}{\sqrt{1-\dfrac{4}{9}}} = 1.34$; ***[1]***

so energy of one particle = 1.34 $m_0 c^2$; ***[1]***

therefore total energy = 2.68 $m_0 c^2 \approx 2.7\ m_0 c^2$; ***[1]***

[3 max]

Full credit also possible if candidate attempts to use relativistic momentum / energy and momentum / velocity relationships.

(b) (i) attempted use of addition of velocities formula; ***[1]***

correct substitution; ***[1]***

to give $u_x = \dfrac{\dfrac{2}{3}c + \dfrac{2}{3}c}{1 + \left(\dfrac{2}{3} \times \dfrac{2}{3}\right)} = \dfrac{12}{13}c = 0.923c$; ***[1]***

ECF possible in following parts so long as this answer is not greater than c.

[3 max]

(ii) realisation that total momentum = momentum of Q; ***[1]***

calculation of $\gamma = \dfrac{1}{\sqrt{1-\left(\dfrac{12}{13}\right)^2}} = \dfrac{1}{\sqrt{0.1479}} = 2.6$; ***[1]***

so $p = \gamma m_0 u = 2.6 m_0 \times \dfrac{12}{13} c = 2.4 m_0 c$; ***[1]***

[3 max]

(iii) use of $E^2 = p^2c^2 + m_0^2c^4$; ***[1]***

to give total energy of $Q = 2.6\ m_0c^2$ ***[1]***

with $E_{total} = 2.6\ m_0c^2 + m_0c^2 = 3.6\ m_0c^2$; ***[1]***

[3 max]

(c) the observers do agree on the number of particles and photons formed (but not on their speeds) / OWTTE; ***[1]***

any sensible justification; ***[1]***

e.g. they disagree on the quantity of energy available, but in P's frame not all this energy is 'available' to create particles as there is some initial momentum / the laws of physics must be the same for all inertial observers / etc.

[2 max]

G3. gravitational red shift is shift in frequency between two identical clocks at different heights in a gravitational field / OWTTE; ***[1]***
photons are shifted to a lower frequency as they 'climb' out of field – *i.e.* shifted towards the red end of the spectrum / OWTTE; ***[1]***

Each valid point outlining a relevant experiment award ***[1]*** *each up to* ***[3 max]****.*

examples of acceptable experiments include:
Pound-Rebka
gamma rays sent up a building;
frequency of Gamma rays measured;
frequency at top lower than measured at bottom;
etc.

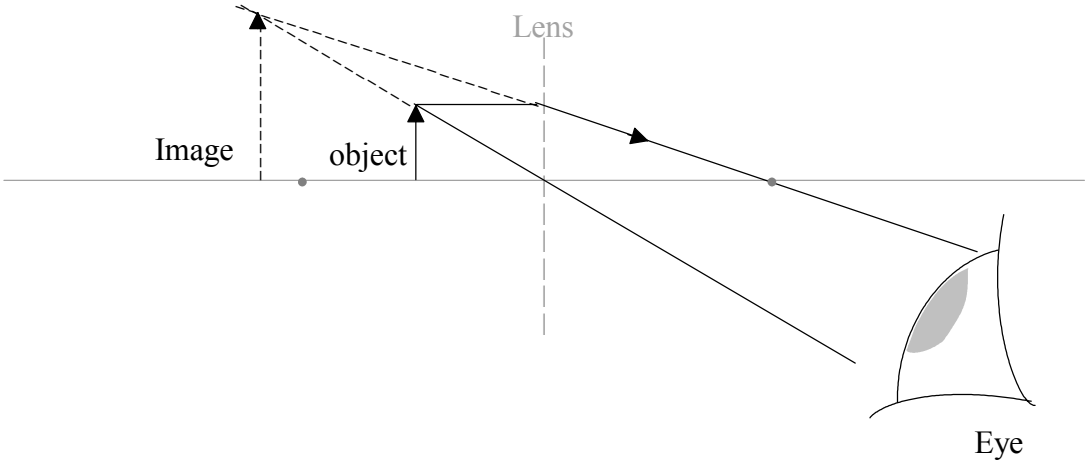
Atomic clock measurements
two atomic clocks 'synchronised';
one clock sent to high altitude then recovered;
clock sent to high altitude lagged behind control;
etc.

[5 max]

OPTION H — OPTICS

H1. (a) labelled object located between f and the lens; ***[1]***
two correct rays drawn diverging after passing through lens; ***[1]***
rays extrapolated back to locate labelled image; ***[1]***
position of eye correctly labelled; ***[1]***
*Incorrect object position can only gain a maximum of **[1]** e.c.f mark (for two correct rays).*

[4 max]



(b) (i) image height = 2 × 1.5 cm = 3.0 cm ***[1 max]***

(ii) object distance = 6 cm; ***[1]***
justification ***[1]***
either use of $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ *with* $v=-2u$*;*
or a scale diagram

[2 max]

(c) as lens moves away, linear magnification increases; ***[1]***
appropriate reasoning; ***[1]***
Accept either ray diagrams or appropriate mathematical arguments.

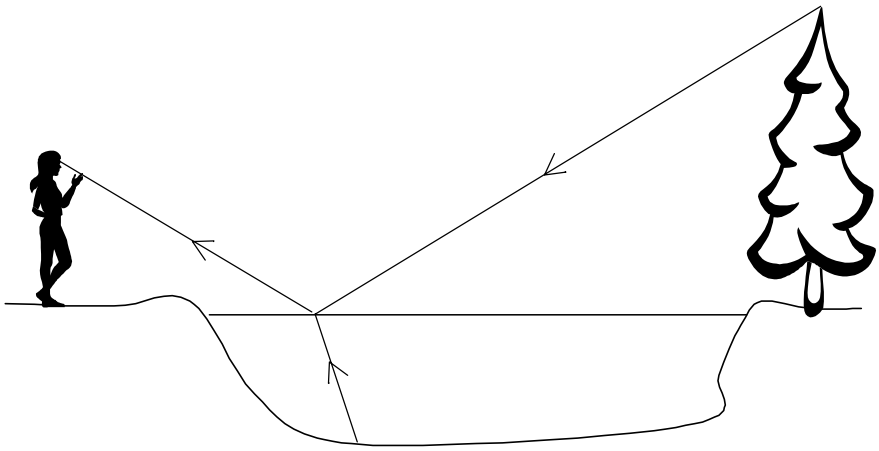
[2 max]

(d) upright image seen at ‘infinity’ / OWTTE; ***[1]***
rays are parallel; ***[1]***
reject blurred or no image

[2 max]

H2. (a) (i) ray from top of tree hitting point **nearer to Caroline** than the tree and then reflecting to eye ***[1 max]***

(ii) ray hitting **same point**, from the bottom of the pond, ***[1 max]***
The exact position would need to be found by trial and error so allow some mistakes but reject rays that clearly do not conform with laws of reflection or refraction.

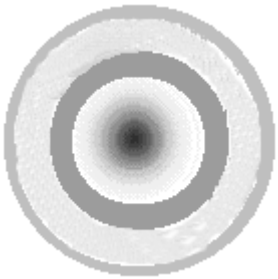


(b) polaroid absorbs light that is polarised (in one direction); ***[1]***
reflected light is polarised to some extent; ***[1]***
so reflected rays preferentially absorbed thus reflected image removed; ***[1]***
[3 max]

H3. (a) any appropriate experiment that shows particle nature of light; ***[1]***
e.g. Compton scattering or photoelectric effect
any relevant detail; ***[1]***
[2 max]

(b) any appropriate experiment that shows wave nature of light; ***[1]***
e.g. refraction or diffraction or interference
any relevant detail; ***[1]***
[2 max]

H4. (a) idea of maximum / minimum / maximum at different angles; ***[1]***
central circle… (rather than point or line); ***[1]***
…with further minimum / maximum in rings; ***[1]***



[3 max]

(b) use of sin $\theta = \frac{1.22\,\lambda}{b}$; ***[1]***

to give $\theta = \frac{1.22 \times 4.5 \times 10^{-7}}{0.3} = 1.83 \times 10^{-6}$ radians; ***[1]***

[2 max]

Missing the 1.22 factor looses a mark but watch for e.c.f. in subsequent questions.

(c) central maximum is $2 \times 1.83 \times 10^{-6} = 3.66 \times 10^{-6}$ radians across; ***[1]***
therefore width $= 3.66 \times 10^{-6} \times 0.9$ m $= 3.3 \times 10^{-6}$ m $= 3.3\,\mu$m; ***[1]***
[2 max]

(d) (i) when two sources are just distinguishable, the maximum of one diffraction pattern coincides with the first minimum of the other diffraction pattern / OWTTE ***[1 max]***

(ii) maximum angular separation $= 1.83 \times 10^{-6}$ radians; ***[1]***
maximum actual separation $= 1.83 \times 10^{-6} \times 10^{20}$ m
$\approx 2 \times 10^{14}$ m; ***[1]***
[2 max]