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MARKSCHEME

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PHYSICS

Standard Level

Paper 3

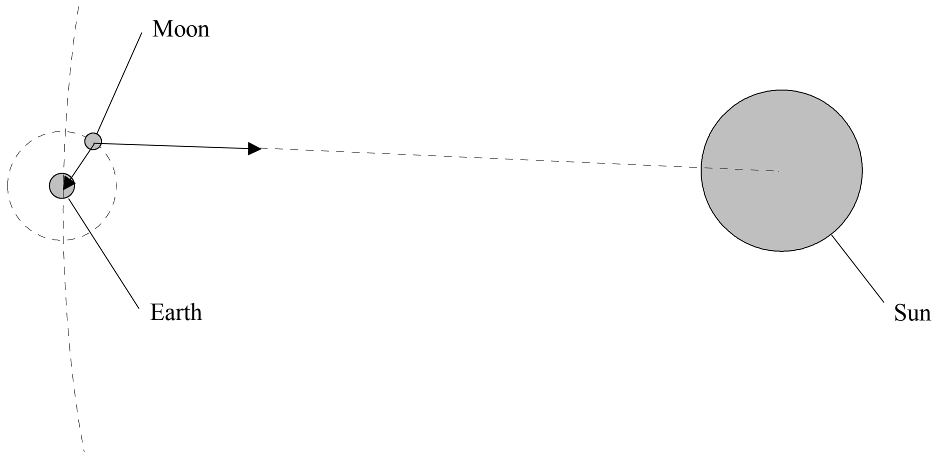
21 pages

OPTION A — MECHANICS EXTENSION

A1. (a) for two point masses, the gravitational force is *proportional* to the *product of the masses…*; ***[1]***
… and *inversely* proportional to the *square* of the separation of two masses; ***[1]***
Accept formula version for full marks provided the symbols are defined.

[2 max]

(b)



arrow from centre of Moon towards centre of Earth; ***[1]***
arrow from centre of Moon towards centre of Sun; ***[1]***
Accept arrows if within half a radius of the centre.
Correct idea but sloppy arrows should still gain credit.

[2 max]

(c) attempted use of $F = \dfrac{G\,m_1\,m_2}{r^2}$
for Earth / Moon AND Earth / Sun systems; ***[1]***
correct rearrangement; ***[1]***

ratio $= \dfrac{M_E}{{r_E}^2} \times \dfrac{{r_S}^2}{M_S} = \dfrac{5.98\times10^{23}}{1.99\times10^{30}} \times \left(\dfrac{1.5\times10^{11}}{3.84\times10^{8}}\right)^2$

to give ratio $= 0.459 = 4.59\times10^{-1}$ (no units); ***[1]***

[3 max]

(d) Moon would (still) orbit the Sun; ***[1]***
time of orbit the same $\simeq$ 1 year or orbital distance roughly the same as before; ***[1]***
any relevant extra detail or explanation or discussion of ideas; ***[1]***
e.g. gravitational attraction to the Sun is still present etc.
Actual answer depends on the velocity of the Moon when the Earth was ‘removed’, giving an elliptical orbit. Award full marks to candidates who understand the principles but are unable to give a concise answer.
N.B. reject the idea the Moon is kept in current orbit around the Sun as a result of its attraction to the Earth.

[3 max]

A2. (a) one arrow towards the right along (or parallel to) the line of collision ***[1 max]***
Ignore magnitude of arrow and accept if shown on diagram 1.

(b) attempt at application of conservation of momentum; ***[1]***
at least one correct resolving of velocity into appropriate components; ***[1]***
correct setting up of the equation along the original direction; ***[1]***

$$m(v\cos\theta) + m(0.2\cos 30^\circ) = m\ (0.5)$$

correct setting up of the equation at right angles; ***[1]***

$$m(v\sin\theta) = m(0.2\sin 30^\circ)$$

correct answer for speed; ***[1]***

$$v = 0.34\ \mathrm{m\,s^{-1}}$$

correct answer for direction; ***[1]***

$$\theta = 17^\circ$$

where θ is the angle between v and the line of collision

[6 max]

(c) correct calculation of KE before; ***[1]***

$$\mathrm{KE_{before}} = 0.5 \times 0.2 \times (0.5)^2 = 0.025\ \mathrm{J}$$

correct calculation of KE after; ***[1]***

$$\mathrm{KE_{after}} = 0.5 \times 0.2 \times (0.2)^2 + 0.5 \times 0.2 \times (0.34)^2 = 0.016\ \mathrm{J}$$

correct answer; ***[1]***

Energy lost $= 0.025 - 0.016 = 0.009$ J;

[3 max]

OPTION B — ATOMIC AND NUCLEAR PHYSICS EXTENSION

B1. (a) use of $p = \frac{h}{\lambda}$; *[1]*

to give 6.6×10^{-24} kg m s^{-1}; *[1]*

[2 max]

(b) use of $\text{KE} = \frac{p^2}{2m}$; *[1]*

correct substitution; *[1]*

to give 2.4×10^{-17} J; *[1]*

[3 max]

(c) use of $V = \frac{\text{KE}}{\text{e}}$; *[1]*

to give 150 V; *[1]*

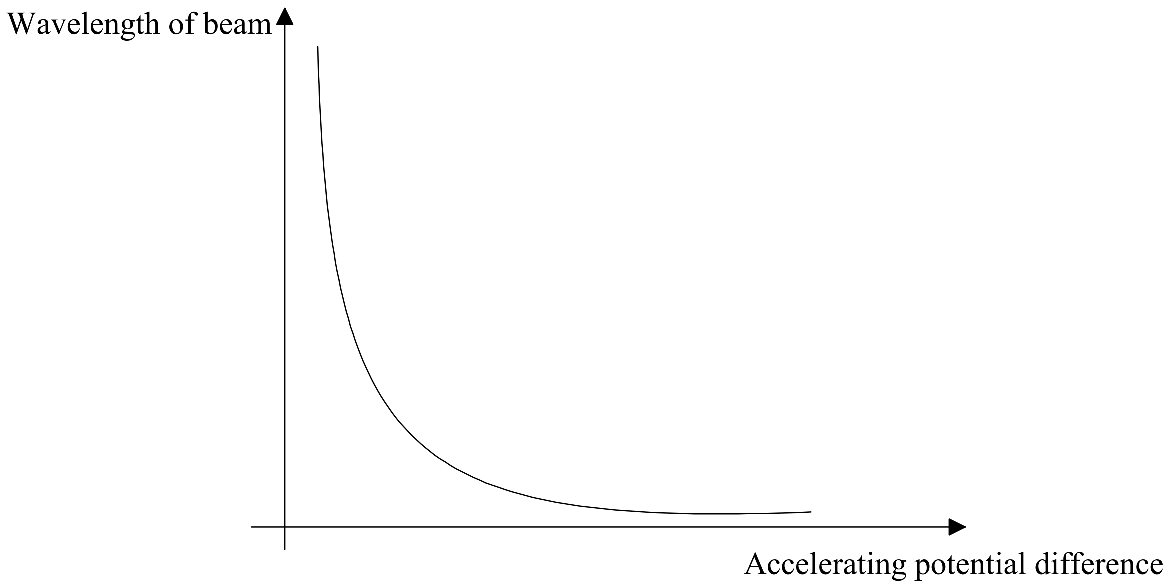
[2 max]

(d) any graph that shows λ always decreasing as V increases…; *[1]*

…that is non linear…; *[1]*

…that does not cross either axis; *[1]*

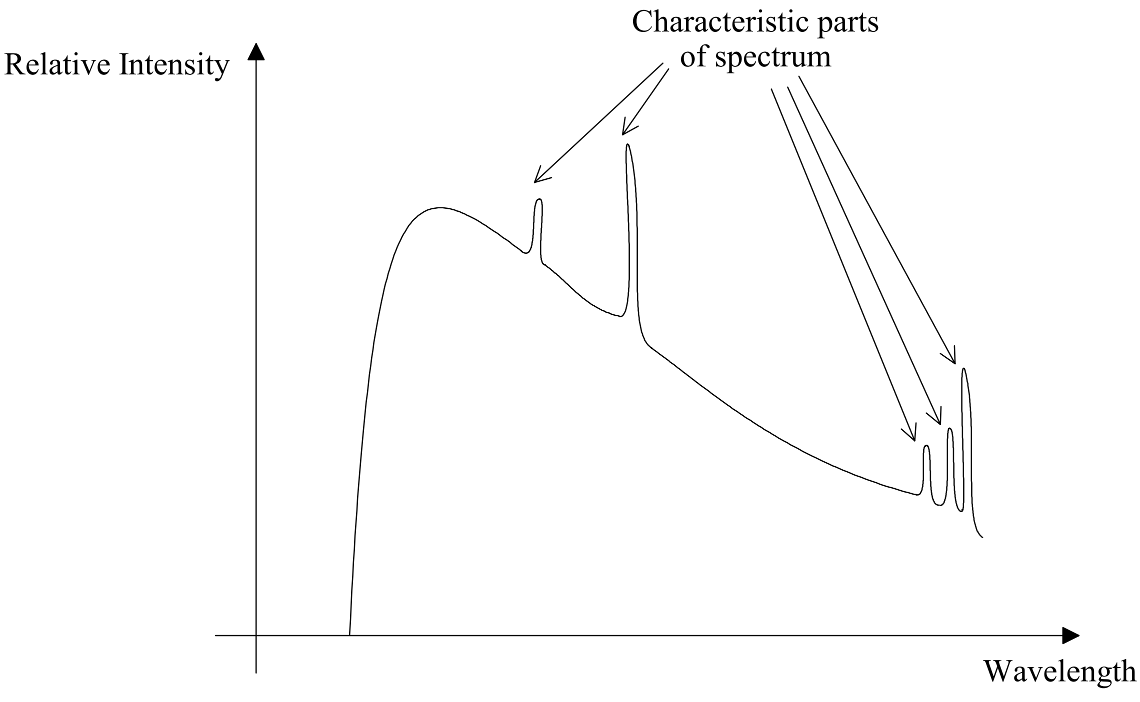
[3 max]



B2. (a) reaction I : Carbon –15 decaying into Nitrogen –15; ***[1]***
since total mass of Carbon nucleus is greater; ***[1]***
*Accept Carbon has smaller mass defect / binding energy per nucleon / OWTTE; accept answer without reasons or with incorrect reasons for **[1]**.*
[2 max]

(b) mass defect in reaction = 15.007 306 – (14.996 265 + 0.000 549) ***[1]***
= 0.010 492; ***[1]***
use of $E = m\,c^2$
or correct handling of units to give …; ***[1]***
…energy released = 9.77 MeV $= 1.56 \times 10^{-12}$ J; ***[1]***
[4 max]
*Award **[3]** if mass of beta particle is ignored giving a mass defect of 0.011 041 u and an energy of 10.3 MeV* $= 1.65 \times 10^{-12}$ J;

B3. (a) two peaks labelled as characteristic ***[1 max]***
Accept two (or more) peaks labelled as sufficient for the mark



(b) Electrons in beam strike (inner) electrons in target…; ***[1]***
… promoting them to a higher energy level…; ***[1]***
… as they fall back down they emit X-rays / OWTTE; ***[1]***
*If candidates have wrongly identified the characteristic part on the graph and gone on to correctly describe the mechanism of the 'breaking radiation', they can get up to **[1]** out of **[3 max]** as e.c.f.*

OPTION C — ENERGY EXTENSION

C1. (a) energy from Sun → thermal energy in the land / atmosphere…; *[1]*
… some of this transformed into KE of air molecules / convection currents in air / OWTTE; *[1]*
[2 max]

(b) any sensible advantage; *[1]*
e.g. once built: no 'fuel' cost; renewable; etc.
reject bald 'cost' without further detail
any sensible disadvantage; *[1]*
e.g. unreliable; ugly; etc.
reject 'cost' without further detail
[2 max]

(c) correct substitution of all values; *[1]*

$$P = 0.5\left(\pi \times 30^2\right) \times 1.3 \times 20^3$$

to give $P = 1.470 \times 10^7$ W $\approx 1.5 \times 10^7$ W $= 15$ M W; *[1]*
[2 max]

(d) (i) use of Efficiency = power out / power in / OWTTE; *[1]*
to give Efficiency = 0.204 ≈ 20 %; *[1]*
[2 max]

(ii) *each sensible reason award* ***[1]*** *mark up to* ***[2 max]***
e.g. energy lost in friction in the axle / OWTTE;
energy lost as heat in the wires;
above assumes wind completely stopped etc.;
Reject 'friction' and 'heat loss' without further detail.
[2 max]

C2. (a) (i) A $\rightarrow$ B **and / or** C $\rightarrow$ D ***[1 max]***

(ii) B $\rightarrow$ C **and / or** D $\rightarrow$ A ***[1 max]***

(b) A $\rightarrow$ B **and** B $\rightarrow$ C ***[1 max]***

(c) use of efficiency $= \dfrac{(T_1 - T_2)}{T_1}$;

and at least one conversion into kelvins; ***[1]***

to give efficiency $= \dfrac{200}{673} = 0.297 = 30\,\%$; ***[1]***

[2 max]

(d) (i) A $\rightarrow$ B ***[1 max]***

(ii) use of efficiency $= \dfrac{\text{work out}}{\text{total heat in}}$; ***[1]***

to give work out = 0.297×1000 J $\approx$ 300 J; ***[1]***

[2 max]

(ii) use of energy absorbed = work out + energy rejected; ***[1]***

to give energy rejected = 1000 – 300 = 700 J; ***[1]***

[2 max]

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]

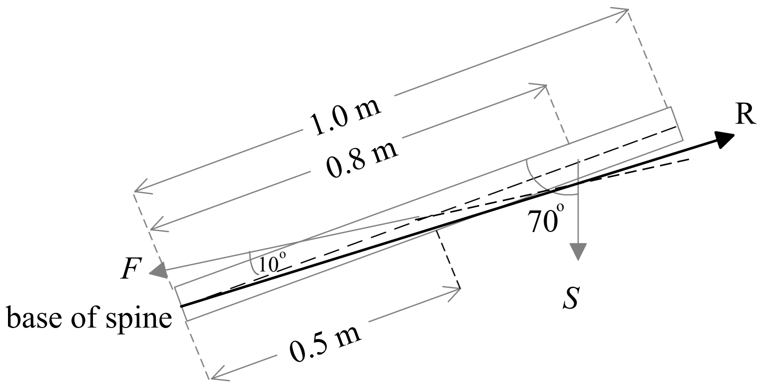
(e) from graph, hearing loss = –20 dB; ***[1]***
normal hearing at this frequency is 10^{-12} W m^{-2} seen or implied; ***[1]***
calculation (or otherwise) give 20 dB loss = 10^{-10} W m^{-2} ; ***[1]***
[3 max]

(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]

Accept 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) × 0.8 (= 0.752 S); ***[1]***
[2 max]

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

OPTION E — HISTORICAL PHYSICS

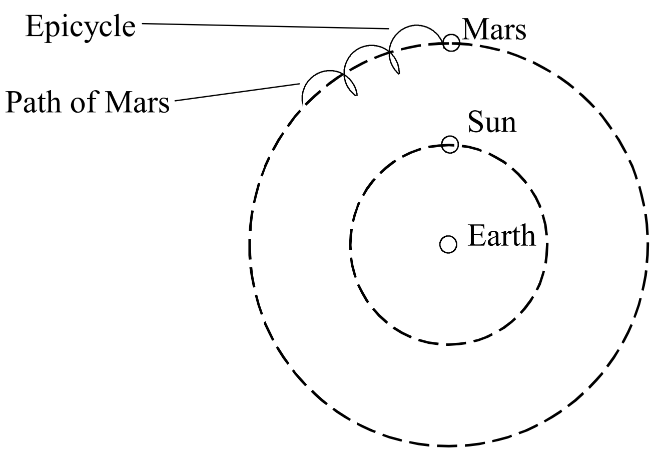
E1. (a) Aristotle: natural place of smoke is up / heavens whereas natural place of stone is on ground / OWTTE; ***[1]***
Galileo: stone falls with uniform acceleration due to gravitational force; ***[1]***
smoke rises as it is displaced by more dense air / OWTTE; ***[1]***
[3 max]

(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]

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…/ OWTTE; ***[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 / OWTTE; ***[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]

F2. (a) Y axis: Luminosity (relative to the Sun) or absolute magnitude; ***[1]***
reject 'magnitude'
X axis: (decreasing) temperature or spectral class (OBAFGKMN); ***[1]***
Accept 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 up the main sequence 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 $T = \dfrac{2.90\times10^{-3}}{5\times10^{-7}} = 5800\text{ K}$; ***[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]

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 $\gamma = \dfrac{\Delta t}{\Delta t_0} = \dfrac{10}{6} = 1.67$ ***[1 max]***

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

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

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

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

[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 $\Delta t_0 = \dfrac{6}{1.67} =$ 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 steps 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) $100 \dfrac{Me\ V}{c^2}$ ***[1 max]***

accept $90 \rightarrow 110 \dfrac{Me\ V}{c^2}$

(b) evidence of reading from graph when mass = $200 \dfrac{Me\ V}{c^2}$; ***[1]***

speed ≈ 0.87 c; ***[1]***

above range gives *0.82 c → 0.92 c*

[2 max]

(c) no; ***[1]***

any sensible discussion of the ideas; ***[1]***

e.g. As velocity increases the mass increases the constant force will produce less acceleration / graph is asymptotic to velocity = c line / etc.

reject 'nothing can travel faster than the speed of light' as an explanation.

[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

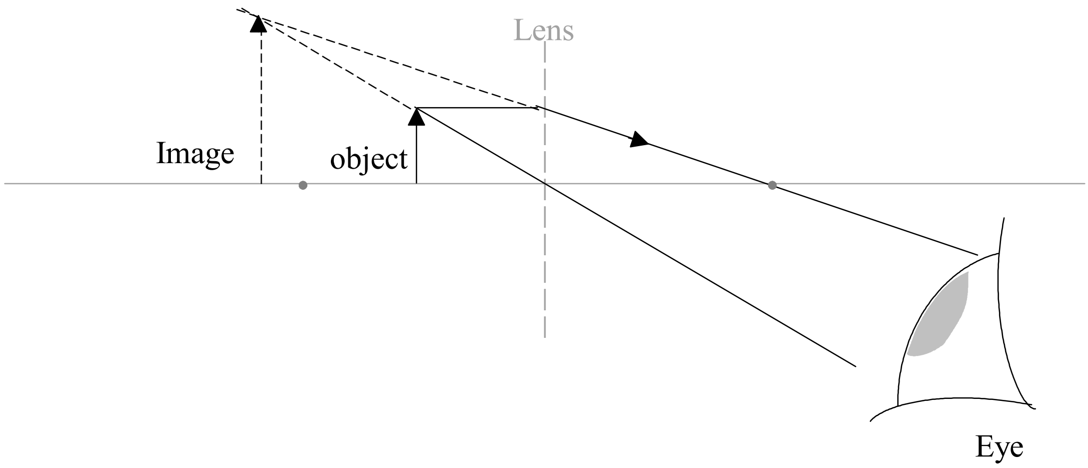
two atomic clocks 'synchronised';
one clock sent to high altitude then recovered;
clock sent to high altitude lagged behind control
etc.

[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.

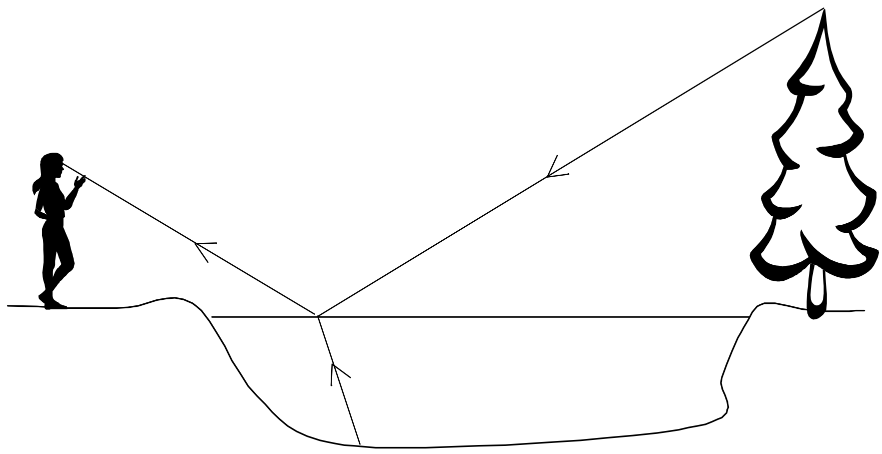
[2 max]

(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]