INTERNATIONAL BACCALAUREATE
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MARKSCHEME

May 2002

PHYSICS

Higher Level

Paper 3

22 pages

Subject Details: **Physics HL Paper 3 Markscheme**

General

A markscheme often has more specific points worthy of a mark than the total allows. This is intentional. Do not award more than the maximum marks allowed for part of a question.

When deciding upon alternative answers by candidates to those given in the markscheme, consider the following points:

- Each marking point has a separate line and the end is signified by means of a semicolon (;).
- An alternative answer or wording is indicated in the markscheme by a '/'; either wording can be accepted.
- Words in (…) in the markscheme are not necessary to gain the mark.
- The order of points does not have to be as written (unless stated otherwise).
- If the candidate's answer has the same 'meaning' or can be clearly interpreted as being the same as that in the mark scheme then award the mark.
- Mark positively. Give candidates credit for what they have achieved, and for what they have got correct, rather than penalising them for what they have not achieved or what they have got wrong.
- Remember that many candidates are writing in a second language. Effective communication is more important than grammatical accuracy.
- Occasionally, a part of a question may require a calculation whose answer is required for subsequent parts. If an error is made in the first part then it should be penalised. However, if the incorrect answer is used correctly in subsequent parts then **follow through** marks should be awarded. Indicate this with **'ECF'**, error carried forward.
- Units should always be given where appropriate. Omission of units should only be penalised once. Indicate this by **'U-1'** at the first point it occurs. Ignore this, if marks for units are already specified in the markscheme.
- Deduct **1 mark in the paper** for gross sig dig error *i.e.* for an **error of 2 or more digits**.

e.g. if the answer is 1.63:

2	*reject*
1.6	accept
1.63	accept
1.631	accept
1.6314	*reject*

Indicate the mark deduction by **'SD-1'**. However if a question specifically deals with uncertainties and significant digits, and marks for sig digs are already specified in the markscheme, then do <u>not</u> deduct again.

OPTION D — BIOMEDICAL PHYSICS

D1. (a) (i) viscosity ***[1 max]***

(ii) Q: $\frac{m^3}{s}$ *or* $m^3\,s^{-1}$; ***[1]***

η: $\text{N m}^{-2}\,\text{s}$ – *also accept Pa s;* ***[1]***

derived from the definition: $\frac{(N\,m^{-2})}{(m\,s^{-1}/m)}$

or Poiseuille's equation: $(N\,m^{-2})m^4\,m^{-1}\left(\frac{m^3}{s}\right)^{-1}$

If derived from Poiseuille's equation, there is a possibility of ECF from $m^3\,s^{-1}$.

[2 max]

(b) (i) for constant Q, $\Delta P \propto r^{-4}$; ***[1]***

$\frac{r_B}{r_A}=\frac{1}{2}$; ***[1]***

$\frac{\Delta P_B}{\Delta P_A}=\left(\frac{1}{2}\right)^{-4}=16\times$; ***[1]***

the pressure drop across tube B must be $16\times$ that across tube A.

[3 max]

(ii) $\Delta P \propto$ resistance, so $R_B = 16\,R_A$; ***[1 max]***

(iii) this is a parallel combination: $\frac{1}{R_{comb}}=\sum\frac{1}{R_i}$; ***[1]***

$\Rightarrow \quad R_{comb}=\frac{R}{4}$; ***[1]***

[2 max]

(c) (i) *Award **[2 max]** for three **or** four correct labels, **[1]** for two correct labels and **[0]** if only one label is correct.*

Label 1 = aorta — Label 2 = arteries *or* arterioles

Label 3 = capillaries — Label 4 = veins *or* venules

The answers to (ii) and (iii) below rest on the "conservation of matter" and the incompressibility of blood.

(ii) the same blood flow rate Q; ***[1]***
must be carried by a greater cross sectional area of vessels, hence blood velocity must be reduced; ***[1]***

[2 max]

(iii) heart output $= \text{Area} \times v_{\text{average}}$; ***[1]***

$\Rightarrow v_{\text{average}} = \dfrac{100\,(\text{cm}^3\,\text{s}^{-1})}{8.0\,\text{cm}^2} = 12\,\text{cm}\,\text{s}^{-1} = 10\,\text{cm}\,\text{s}^{-1}$ *(1 significant digit)*; ***[1]***

[2 max]

D2. (a) mass of water $\propto L^2$; *[1]*

normal body mass $\propto L^3$; *[1]*

$$\Rightarrow \text{ ratio} = \frac{\text{mass of water}}{\text{normal body mass}} \propto \frac{L^2}{L^3} = \frac{1}{L}$$

[2 max]

(b) $\dfrac{\text{ratio human}}{\text{ratio fly}} \approx \dfrac{L_{fly}}{L_{human}}$; *[1]*

*This assumes the "proportionality constants" are equal which, given the totally different nature of the animals, is stretching things a bit! If any candidate makes an explicit (sensible) reference to this aspect they should be rewarded, with up to **[1]** subject to the **[3 max]**.*

$L_{fly} \approx 10\,\text{mm}$ *(accept ~5 – 20 mm)*; *[1]*

$L_{human} \approx 1700\,\text{mm}$ *(accept ~ 1 500 – 2 000 mm)*; *[1]*

$\Rightarrow$ ratio fly $\approx$ ratio human $\times \dfrac{L_{human}}{L_{fly}} = \dfrac{1\,\% \times 1700}{10} = 170\,\%$ *(accept ~75 – 400 %)*; *[1]*

(accept a maximum of 2 significant digits)

[3 max]

D3. (a) sound at frequencies $\geq$ 20 kHz ***[1 max]***

(b) *Essential points:*

pulses of ultrasound are emitted / sent out; *[1]*

the **reflected pulses are detected** and **timed**; *[1]*

this gives the **distance to the boundary** and so it can be mapped; *[1]*

*Additional information for which **[1]** can be awarded:*

the pulses reflect off "boundaries" within the body where the refractive index changes

the reflections are weak

there is strong absorption

[3 max]

(c) high frequency → small wavelength; *[1]*

→ better resolution; *[1]*

[2 max]

(d) to **eliminate any air layer** between the transducer head and the body / skin; *[1]*

(makes a better acoustic match)

$\Rightarrow$ better transmission into the body *(less reflection)*; *[1]*

[2 max]

(e) *Award **[2 max]** for any **two** of the following.*

when "looking" at – soft tissue and/or fluid; *[1]*

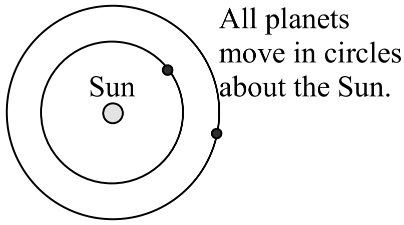
– organs, *etc*. that may be more susceptible to damage; *[1]*

– embryos / foetuses; *[1]*

when looking at a "real-time" image; *[1]*

OPTION E — HISTORICAL PHYSICS

E1. (a) (i) all planetary paths **must** be shown as *(or somehow indicated to be)* circles



[1 max]

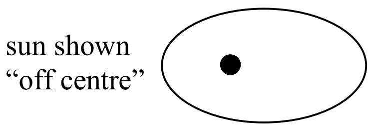
(ii) Sun and Stars' motion is apparent; ***[1]***
due to the spin of the Earth in the "opposite" sense; ***[1]***
[2 max]

(b) (i) *Award* ***[1 max]*** *for any* ***one*** *of the following.*
phases of Venus; ***[1]***
varying brightness of planets; ***[1]***
"rough" features on the Sun and Moon (hence they are not "perfect spheres"); ***[1]***
Sun rotates; ***[1]***
Jupiter has moons; ***[1]***

(ii) in a geocentric model, the Earth is at the centre of "all heavenly motion"; ***[1]***
why an explanation of the stated observation fails in such a model; ***[1]***
The first two observations above are "inexplicable" / have no natural explanation and the last three are philosophically not acceptable in such a model.

[2 max]

(c) orbits were ellipses not circles; ***[1]***
with the Sun at one focus; ***[1]***



A good diagram can be a full description.

[2 max]

(d) (i) an empirical relationship is a rule or set of rules that allow certain events / observations to be predicted but with no underlying physical principle.
or an empirical relationship provides a "numerical" agreement … .
or guess a formula which fits the facts … .

[1 max]

(ii) Newton's Laws of Motion; ***[1]***
Newton's Law of Gravity; ***[1]***
[2 max]

E2. (a) (i) 19th century *(accept 1800s, etc.)* ***[1 max]***

(ii) the (separate) condenser was not part of the Newcomen engine. ***[1 max]***

(iii) the temperatures of the "hot" and "cold" reservoirs; ***[1 + 1]***
[2 max]

(b) (i) "*high quality*" – heat into boiler / high temperature steam
Accept coal ***or*** *fuel.*
"*low quality*" – low temperature steam / heat out at condenser / atmosphere
Clearly, once one source has been identified the other follows.
[1 max]

(ii) degraded (thermal) energy is: at a "lower temperature" *or* of "lower quality" *or* "less ordered" / more "spread out" (over a large number of molecules); ***[1]***

To receive the second mark, these have to be qualified along the lines of:
"harder" to extract useful work from *or* "harder" to transform into work *or* becomes "less available" to do useful work; ***[1]***

Accept answers that are specific to the situation for the second mark.
e.g. degraded energy is the thermal energy of the air, warmed via the condenser / steam engine. It is no longer available to do work / etc.,
[2 max]

(c) *Award any sensible statement along the lines of:*
entropy change is a measure of energy degradation / is directly related to Q_{COLD}, the amount of degraded energy; ***[1]***

Award any additional qualification:
in irreversible processes the amount of degraded energy is always > 0, just as the entropy change > 0; ***[1]***
entropy is high when energy is "disordered" / spread over many molecules; ***[1]***
the greater the degradation of the energy, the greater the entropy change; ***[1]***
the greater amount of degraded energy the greater the entropy change; ***[1]***
[2 max]

E3. *The existence of a cut-off frequency and the "time delay" are linked. The wave model does not predict a cut-off frequency because one just has to increase the intensity or wait for a longer time and eventually the metal surface will absorb enough energy to emit an electron.*

the **photon-electron interaction is a one-to-one**, "billiard-ball" type "collision"; ***[1]***

this means that, (if the conditions are such that the photoelectric effect takes place at all), there can **never be a "time delay"**, (even at the lowest intensities); ***[1]***

there is a minimum amount of energy required to knock out the electron (the work function) – either the photon has enough energy or it has not; ***[1]***

for the photon, $E = hf$, hence a minimum $E \Rightarrow$ a minimum f; ***[1]***

Award additional marks for other, nontrivial, ***relevant*** *information up to* ***[4 max]***

[4 max]

E4. (i) mass–energy not conserved; mass-energy LHS < mass–energy RHS; ***[1]***

$n \to p^+ + e^- + \bar{\nu}$; ***[1]***

Must be an anti-neutrino to balance the lepton number.

[2 max]

(ii) Baryon number not conserved; ***[1]***

minimal change from given (incorrect) decay mode $\Rightarrow \Lambda^0 \to p^+ + \pi^-$; ***[1]***

Also accept $\Lambda^0 \to n + \pi^0$ *(another major decay mode), for even though the properties of the* π^0 *are not explicitly given, they can be inferred.*

Do ***not*** *accept* $\Lambda^0 \to n$ *as this cannot conserve energy and momentum – hard but fair.*

Also accept the decays $\Lambda^0 \to n + e^- + e^+$ *(with or without neutrinos),* $\Lambda^0 \to p^+ + e^- + \bar{\nu}$ *or* $\Lambda^0 \to p^- + e^- + \nu$ *even though these do not occur, they are consistent with the data in the table. However,*

$\Lambda^0 \to n + \pi^- + \pi^+$ does not conserve mass–energy

[2 max]

(iii) momentum not conserved; ***[1]***

$e^- + e^- \to \gamma + \gamma$; ***[1]***

[2 max]

OPTION F — ASTROPHYSICS

F1. (a) (i) Deneb would be bluish and Antares A reddish; ***[1]***
because Deneb is at a higher (surface) temperature; ***[1]***

at higher temperatures a greater proportion of the energy is radiated in the blue part of the visible spectrum; ***[1]***
Accept any sensible reference to temperature.

[3 max]

(ii) Antares A is brighter than Deneb *(accept – about the same brightness)*; ***[1]***
because it has a smaller apparent magnitude; ***[1]***
[2 max]

(iii) Deneb is further away than Antares A; ***[1]***
Deneb's absolute magnitude is smaller ⇒ Deneb's luminosity > Antares A, but it looks fainter; ***[1]***
Do not accept "because the parallax angle is too small to measure" for the second mark.

[2 max]

(b) $d = \frac{1}{0.006}$ pc; ***[1]***

$= 3.26 \times 9.46 \times 10^{15} \times \frac{1}{0.006} = 5.1 \times 10^{18}$, *accept* 5×10^{18} m *(1 significant digit)*; ***[1]***

[2 max]

(c) $L = \sigma A T^4$ and $A = \pi r^2$; ***[1]***

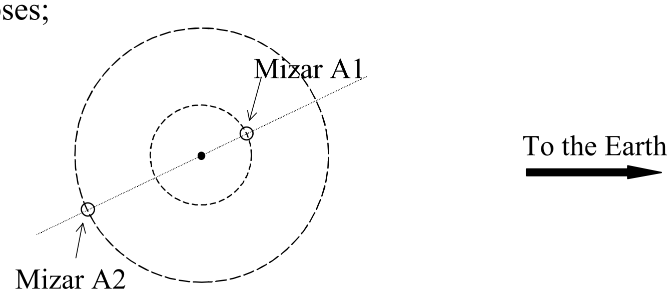
$\frac{L_A}{L_B} = 40$ *(forming the ratio)*; ***[1]***

$= \frac{A_A \times 3000^4}{A_B \times 15000^4} = \frac{\pi r_A{}^2 \times 3000^4}{\pi r_B{}^2 \times 15000^4} = \left(\frac{r_A{}^2}{r_B{}^2}\right) \times \left(\frac{1}{5}\right)^4$; ***[1]***

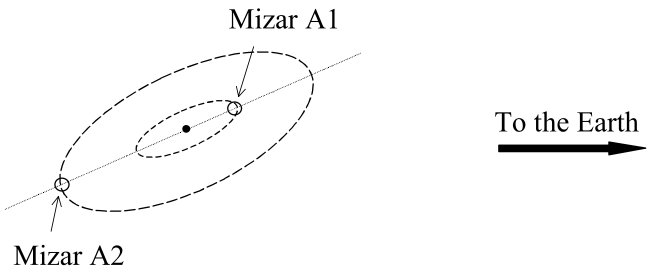
$\Rightarrow \frac{r_A}{r_B} = 5^2\sqrt{40} = 158 = 160$ *(2 significant digits)*; ***[1]***

[4 max]

F2. (a) expect a "plan view"
circles *or* ellipses; ***[1]***



or an "inclined view"



For ***[1]***, ***the diagram*** *should show correct circular* ***or*** *elliptical orbits with the stars on "opposite sides" of the centre of mass.*

Accept other ***meaningful*** */* ***relevant*** *diagrammatic representations.*
when one star is approaching (the Earth), the other is receding; ***[1]***
⇒ a red and (simultaneously), a blue shift; ***[1]***
when the motion is perpendicular (to the line of sight) there is no wavelength shift; ***[1]***
This occurs every half cycle – ***[1]*** *is given for this at (b)*

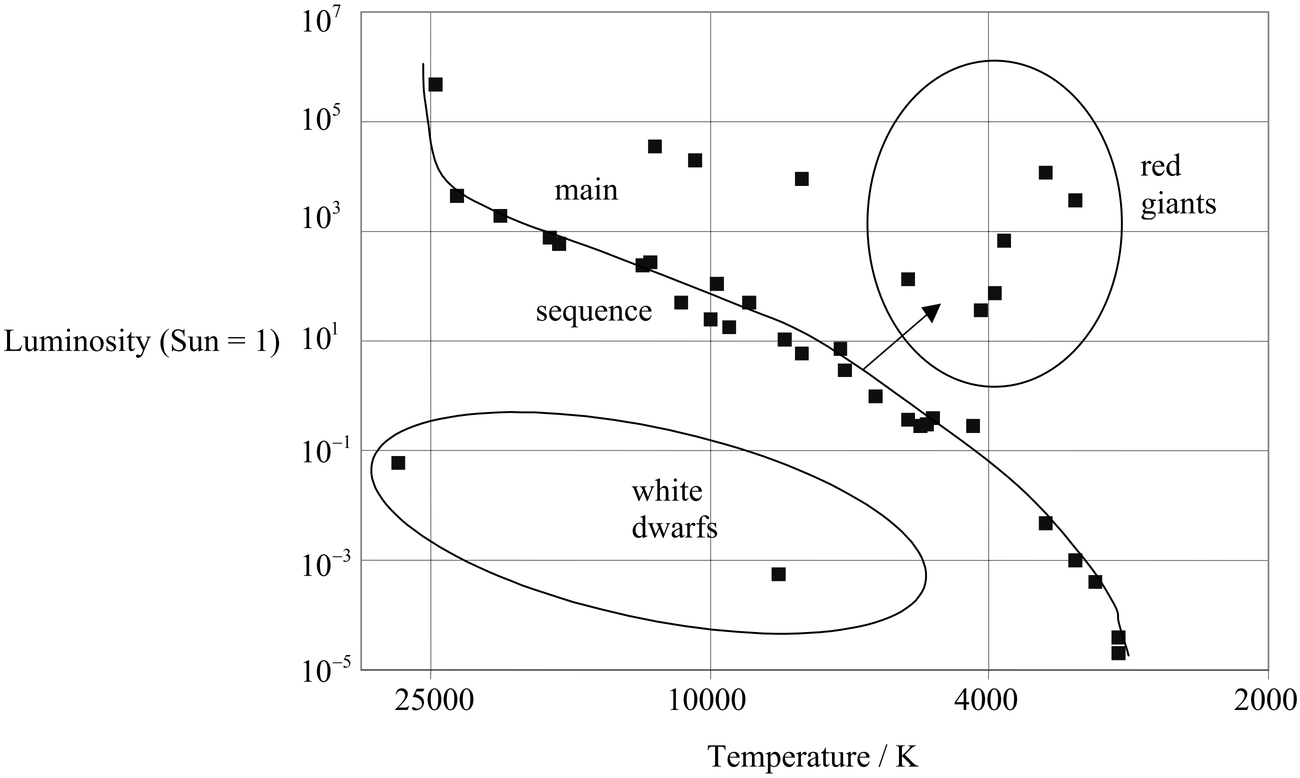
[4 max]

(b) 20 days *(accept 21 days)* ***[1 max]***

(c) *Since the wavelength shift is small use*,
$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$; ***[1]***
$\Rightarrow v = \frac{0.26}{448.3} \times c$; ***[1]***
$= 0.00058c$ (*accept this*) *and* $= 1.7 \times 10^5$ m/s *(2 significant digits)*; ***[1]***
[3 max]

(d) *Limits can be placed on*
the sum of the masses of the stars / the mass of the system ***[1 max]***
Individual velocities would give the individual star masses.

F3. (a) *Award **[0]** for one correct, **[1]** for two correct and **[2 max]** for three correct.*



[2 max]

(b) (i) temperature↓ ; ***[1]***
luminosity ↑ ; ***[1]***
size ↑ ; ***[1]***
[3 max]

(b) (ii) the increased size comes about because the outer layers expand; ***[1]***
After hydrogen burning in the core stops and the core "collapses".
this causes the surface temperature to drop; ***[1]***
and the luminosity to increase; ***[1]***

Note that the mass of the star is only a little > mass of the sun.
*Do not award more than **[1]** in total, for "irrelevant" additional information e.g. hydrogen burning in the core stops; some hydrogen burning continues in the inner layers; core "collapses"; core temperature rises; helium burning begins in the core; etc.*

[3 max]

OPTION G — SPECIAL AND GENERAL RELATIVITY

G1. (a) to measure the speed of the Earth through the ether ***[1 max]***

(b) null result / no detectable velocity ***[1 max]***

(c) to rule out the possibility of an "accidental" null result – at any one time the speed of the Earth, by chance, could be zero; ***[1]***
if a null result was obtained (⇒ speed = 0), at one time (of the year) / in one orientation, then it couldn't be so at a later time / in another orientation; ***[1]***
[2 max]

(d) reference must be made to either (or both) of the hypotheses – "constancy of the speed of light" *or* "all experiments performed in an inertial frame of reference (= "all physical laws") must produce the same results"; ***[1]***
⇒ time differences / phase shifts between the arms do not change with season / orientation. *i.e.* result is independent of orientation / *etc.*; ***[1]***
[2 max]

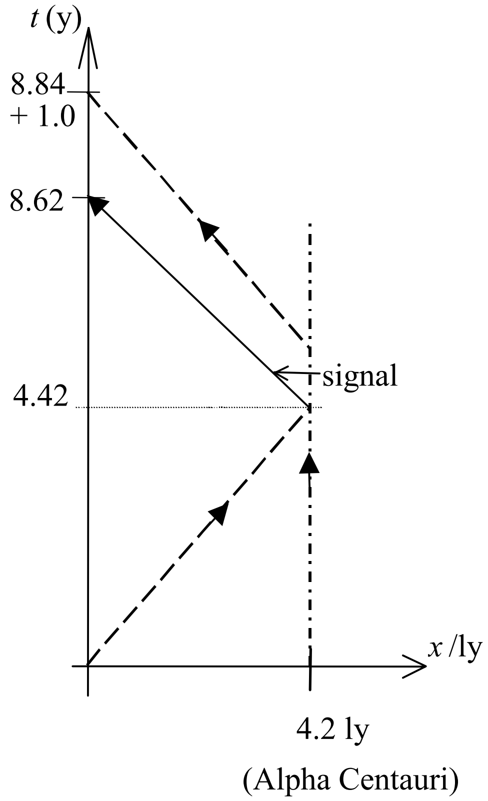
G2. (a) *To achieve **[2 max]**, the values, units and annotation of the diagram must be correct.*

time of arrival at Alpha Centauri = $\frac{4.2}{0.95} = 4.4(2)\text{y}$; **[1]**

time of return to earth $2 \times 4.42 = 8.8(4)\text{y} + 1\text{y}$; **[1]**

Strictly, 2 significant digits only.

Do not penalise omission of " + 1y".



[2 max]

(b) time taken = 4.2 y ⇒ time of arrival = 8.6(2) y; **[1]**

correct "signal path" on diagram; **[1]**

Must be clearly "less steep".

[2 max]

(c) $\gamma = \frac{1}{\sqrt{\left(1 - \frac{v^2}{c^2}\right)}} = 3.2$; **[1]**

$\Delta t_{astro} = 2 \times \frac{4.42}{\gamma}$; **[1]**

= 2.7(6) y; **[1]**

Astro's measure a proper time.

[3 max]

(d) (i) *Award no marks for just saying that this is the "Twin Paradox" as it is not acceptable.*
essential point: (on first appearances), any time difference should be "reversible"; ***[1]***
the (implicit) assumption being that descriptions of the events from the two frames of reference are completely equivalent; ***[1]***
[2 max]

(ii) the two frames of reference are not equivalent; ***[1]***
*and some reasonable (not necessarily "perfect") explanation of why would also receive **[1]**.*
the astronauts must have accelerated in order to have "stopped" and returned
or accelerations tell us who was "really" moving / their frame of reference was non-inertial
or the astronauts had to switch from one inertial frame to another; ***[1]***
[2 max]

G3. (a) (i) 1.7c ***[1]***
(ii) 2.6c ***[1]***
[2 max]

(b) (i) c ***[1]***
(ii) c ***[1]***
[2 max]

(c) correct application of velocity addition formula; ***[2]***
correct result; ***[1]***

$$\text{speed}_{\text{probe/sp. st'n}} = \frac{0.9c + 0.7c}{1 + \dfrac{0.9 \times 0.7c^2}{c^2}} = \frac{1.6c}{1.63} = 0.98c$$

Strictly, the negative of this should be calculated and some candidates may,
i.e.

$$\text{speed}_{\text{probe/sp. st'n}} = \frac{-0.9c - 0.7c}{1 - \dfrac{-0.9 \times 0.7c^2}{c^2}} = \frac{-1.6c}{1.63} = -0.98c$$

However, it is not the intention to get pedantic about the sign; the question asks for "speed".

[3 max]

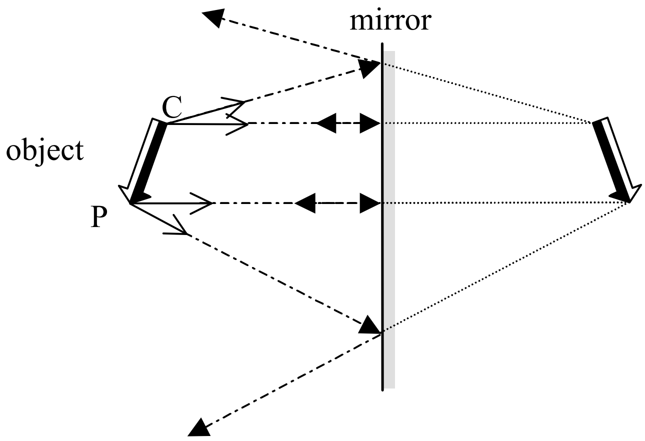
G4. (a) photon energy is increased as it "falls" in the gravitational field; ***[1]***
hence the frequency increases; ***[1]***
[2 max]

(b) $\Delta f = f\,g\dfrac{\Delta h}{c^2} = \dfrac{117.8\times10^6\times9.8\times36\times10^6}{9\times10^{16}}$; ***[1]***
= 0.46 Hz; ***[1]***
Use of $g = 10\,\mathrm{m\,s^{-2}}$ *is perfectly OK, as is 1 significant digit;* ***not*** *3 significant digits.*
[2 max]

(c) the actual frequency shift would be less (*i.e.* the calculation is an overestimate); ***[1]***
since for much of the 36×10^6 m *g* would be less; ***[1]***
Award no marks here if the answers given is "... because g changes." The bare statement that "... this is an overestimate" also receives no marks.
[2 max]

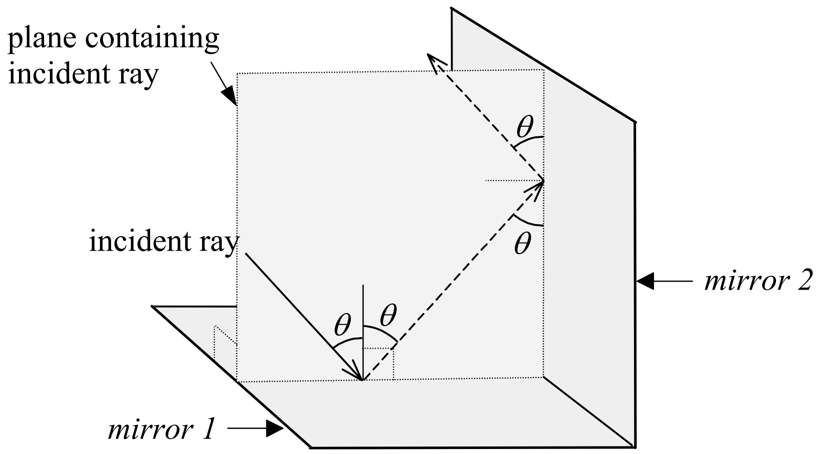
OPTION H — OPTICS

H1. (a) properly extended rays; ***[2]***
Allow for some error / variation.
correct orientation; ***[1]***
(image of "C" closer to the mirror than of "P" and black / white "reversal")



[3 max]

(b) (i) reflected path; ***[1]***
geometric argument based on
angle of incidence = angle of reflection; ***[1]***
and some geometry (alternate angles are equal; complementary angles = 90°; *etc.*); ***[1]***



[3 max]

(ii) *Award **[1 max]** for any **one** of the following.*
rear vehicle / bicycle reflectors
"cats-eyes" reflectors on roads
"corner reflectors" on the Moon
or any other applications

H2. (a) *This is quite difficult to express even if one knows the answer!*

*Award **[2 max]** if the candidate shows a general understanding of the situation (even if poorly expressed). Points that could be mentioned are below.*
some discussion of the behaviour of the particular ray(s) drawn
the role of the mirror
why the image is inverted

*Specifically **any** combination of the following. Refraction details at the lens are not required.*
general quality of ray diagram (ruled lines, accuracy / care taken); ***[1]***
discussion of the role of the mirror; ***[1]***

*Award **[2]** for any **one** correctly drawn ray plus a brief explanation of why it behaves as it does e.g. any **one** of the following.*
any ray through the lens centre will be "reflected" at an equal angle (hence the image must be "inverted"); ***[2]***
any ray from the tip of the object will strike the mirror ⊥ and be reflected and refracted back through the tip; this includes the "⊥ ray" along the principal axis; ***[2]***
rays parallel to the principal axis will be focussed in the image plane (though this is not "immediately" obvious (?)); ***[2]***

***Alternatively**, the answer could be along the lines that the mirror acts as a second identical lens plus a reflection (see Diagram B).*

Diagram A

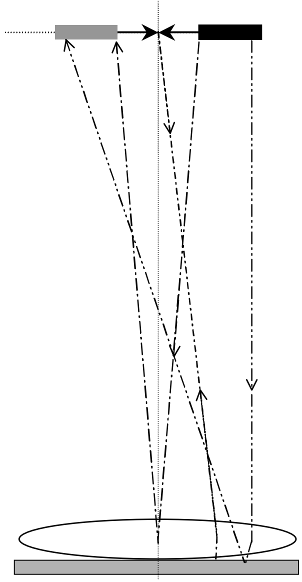
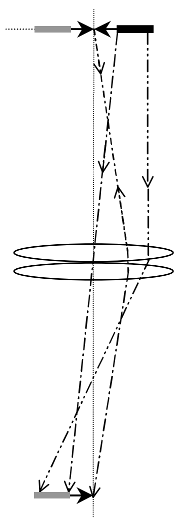


Diagram B



[4 max]

(b) image is real ***[1 max]***

(c) magnification = 1 *(accept same size)* ***[1 max]***

(d) the image will move **closer** to the lens ***[1 max]***

H3. (a) $d \sin \theta = n\lambda$ *(for maxima)*; **[1]**

$\Rightarrow d \sin \theta = 1 \times \lambda$ for $\theta = 0.50^{\circ}$ (the scale can easily be read to 2 significant figures); **[1]**

$\Rightarrow d = \dfrac{434 \times 10^{-9}}{\sin 0.50} = 5.0 \times 10^{-5}$ m (= 0.050 mm); **[1]**

[3 max]

(b) *Award **[1]** per feature shown on the diagram below, up to **[3 max]**.*

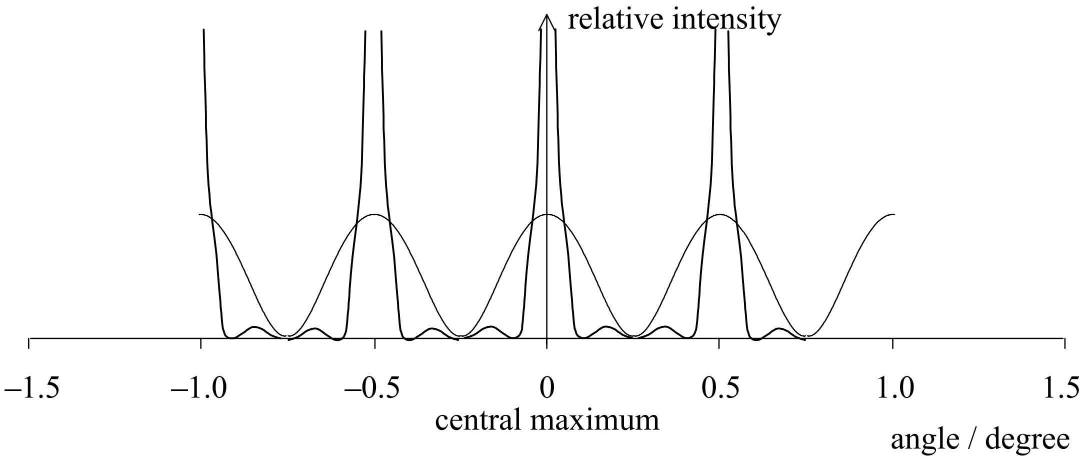
narrower "lines"; **[1]**

maxima in the same positions; **[1]**

greater intensity *(clearly, correct scaling is not required)*; **[1]**

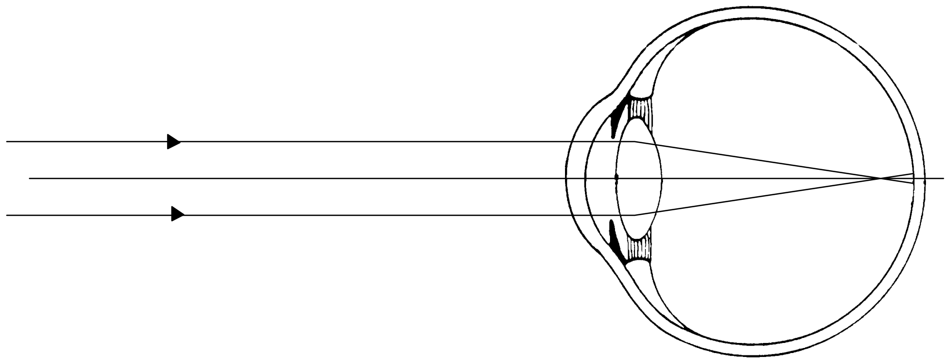
secondary, much smaller, maxima *(there should be two but this is not critical)*; **[1]**

*It is not necessary to show **all** maxima as long as the candidate clearly shows he/she knows what's up e.g. see below*



[3 max]

H4. (a) figure should show **parallel incident rays**;
and **position of focus inside the eyeball**;



[2 max]

(b) diverging ***[1 max]***

(c) the image of a distant object (at ∞) is at $d_i = -0.70\,\text{m}$ (it's on the object side) hence

$\frac{1}{f} = \frac{1}{\infty} - \frac{1}{0.70}$; ***[1]***

$\Rightarrow f = -0.70\,\text{m}$ (confirming it is a diverging lens); ***[1]***

Use of $d_i = +0.70\,m$ receives ***[1]***

[2 max]

(d) (i) $n \equiv \frac{c}{c_{\text{medium}}} = \frac{f\lambda}{f\lambda_{\text{medium}}}$; ***[1]***

$\Rightarrow \lambda_{\text{medium}} = \frac{550}{1.337} = 411\,\text{nm}$ *(3 significant digits)*; ***[1]***

[2 max]

(ii) Rayleigh criterion $\Rightarrow \theta_R = \frac{1.22\lambda}{D}$; ***[1]***

$= \frac{1.22 \times 411 \times 10^{-9}}{4 \times 10^{-3}}$; ***[1]***

$= 1.25 \times 10^{-4}\,\text{rad} = 1.3 \times 10^{-4}\,\text{rad}$ *(2 significant digits)*; ***[1]***

Use of 550 nm $\Rightarrow$ 1.6(7)$\times 10^{-4}$ rad, receives ***[2 max]***.

[3 max]