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N03/430/H(3)M+

MARKSCHEME

November 2003

PHYSICS

Higher Level

Paper 3

19 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 markscheme then award the mark.
- Mark positively. Give candidates credit for what they have achieved, and for what they have got correct, rather than penalizing them for what they have not achieved or what they have got wrong.
- 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 penalized. However, if the incorrect answer is used correctly in subsequent parts then **follow through** marks should be awarded.
- Units should always be given where appropriate. Omission of units should only be penalized once. 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*

However, if a question specifically deals with uncertainties and significant digits, and marks for sig digs are already specified in the markscheme, then do **not** deduct again.

OPTION D — BIOMEDICAL PHYSICS

D1. (a) (i) energy loss $\propto L^2$;
mass $\propto L^3$;
therefore, $Q \propto \frac{1}{L}$;
ratio $\frac{small}{large} = \frac{4}{2\times10^{-2}} = 2\times10^2$; ***[4 max]***

(ii) *Anything sensible such as:*
shape of the mammals can be approximated to cubes / spheres / same fur covering / speciality losses ignored such as very large ears; ***[1 max]***

(b) (i) energy loss per unit mass becomes too great;
to be sustained by metabolism / *OWTTE*;
or *difficult* to maintain constant body temperature in a sudden cold snap / *OWTTE*; ***[2 max]***
*Award state **[1]** and explanation **[1]**.*

(ii) the leg bones would not be able to support larger mammals;
mass increases with r^3 so breaking stress of bones soon reached / *OWTTE*;
or energy production is so large;
that mammal will overheat / *OWTTE*; ***[2 max]***
*Award state **[1]** and explanation **[1]**.*

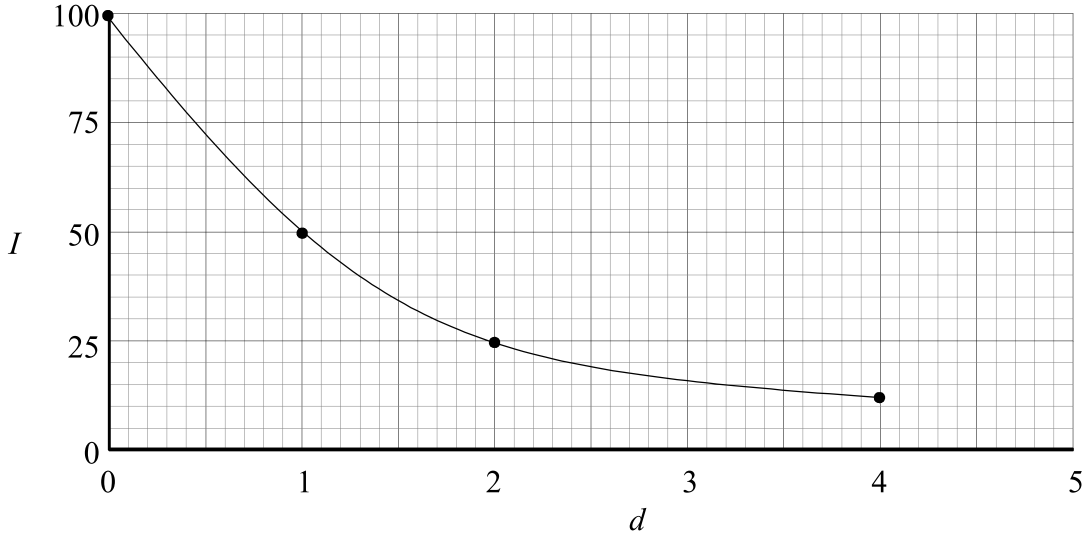
D2. (a) intensity $\propto A^2$;
therefore, ratio of amplitudes $= 10^{-3}$; ***[2 max]***

(b) difference in dB between Carmen and Jorge $= 10 \log\left(\frac{10^{-12}}{10^{-6}}\right)$;
= 60 dB; ***[2 max]***

(c) 3 000 Hz;
since at this frequency she can detect sound at 5 dB below 0 dB / *OWTTE*; ***[2 max]***

(d) 60 ($\pm$5) dB; ***[1 max]***

D3. (a)



*Award general shape **[1]**.*
*A graph that clearly shows exponential dependency receives **[2]**.* ***[2 max]***

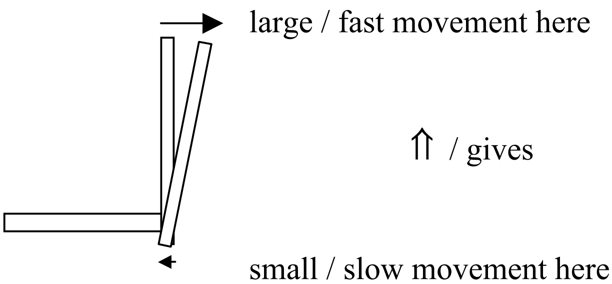
(b) 30 keV
is less attenuated by the muscle;
but is still likely to be well attenuated by the bone; ***[2 max]***
*Right answer on its own does not gain any credit. Award **[1]** for each relevant point in the explanation up to **[2 max]**.*

D4. (a) torque $= 0.024 \times F$;

$\Rightarrow F = \dfrac{12}{0.024} = 500\text{ N}$; ***[2 max]***

(b) *bare statement* – this provides a "movement / speed" advantage;
additional explanation – a small contraction of the muscle (small movement) produces;
– a relatively large / fast movement at the other end of the arm; ***[3 max]***
The second part could be answered through a good diagram.

e.g.



D5. (a) a general statement is adequate here, *e.g.* it allows doses of different types of radiation to be compared for their biological effects;
of course more detailed statements are acceptable, *e.g.* quality factor/RBE compares the biological effectiveness of a given type of radiation to that of [200 keV] X-rays; ***[1 max]***

(b) absorbed dose $= \dfrac{\text{dose equivalent}}{\text{quality factor}}$

$= \dfrac{240\ \mathrm{J\,kg^{-1}}}{14} = 17.1\ \mathrm{J\,kg^{-1}}$;

total energy absorbed $= 17.1 \times 0.015 = 0.257\ \mathrm{J}$;

$=$ number per second $\times$ energy per proton $\times$ time;

exposure time $= \dfrac{0.257}{1.8\times10^{10}\times4.0\times10^{6}\times1.6\times10^{-19}} = 22(.3)\ \mathrm{s}$;

Watch for ECF. ***[4 max]***

OPTION E — THE HISTORY AND DEVELOPMENT OF PHYSICS

E1. (a) (i) acceleration of the Moon at surface of the Earth is given by $M_{moon}g = \frac{K}{R_E^{\ 2}}$;

acceleration of Moon in orbit is given by $M_{moon}g_{orbit} = \frac{K}{(60R_E)^2}$;

therefore, $\frac{g_{orbit}}{g} = \frac{1}{3600}$;

therefore, $g_{orbit} = 10 \times 2.8 \times 10^{-4} = 2.8 \times 10^{-3}\ \text{m s}^{-2}$; ***[4 max]***

(ii) acceleration $= \frac{v^2}{R} = \frac{v^2}{60R_E}$;

$= \frac{4\pi^2(60R_E)}{T^2}$;

$= \frac{40 \times 60 \times 6.4 \times 10^6}{(2.4 \times 10^6)^2}$;

$= 2.7 \times 10^{-3}\ \text{m s}^{-2}$; ***[4 max]***

(iii) *A statement that the two values are sufficiently close to make Newton's assumption correct.* ***[1 max]***

(b) that the force that causes object to fall to the ground;
is the same as that force that the Earth exerts on all bodies in the Universe; ***[2 max]***
***Alternatively**, a clear statement that the law is true for the force between any two bodies. Accept ("or all bodies") in the universe. Award **[1]** for some idea.*

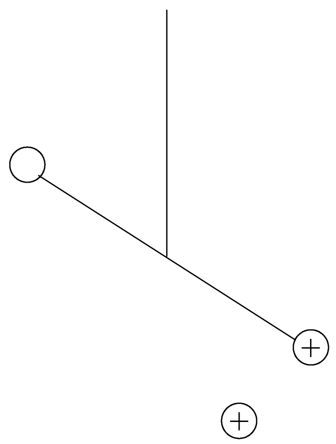
E2. (a) $= \dfrac{kQ^2}{4d^2}$ or $F = \dfrac{Q^2}{16\pi\varepsilon_0 d^2}$; ***[1 max]***

(b) $\dfrac{F}{4}$; ***[1 max]***

(c) the spheres can be assumed to be point charges; ***[1 max]***

(d) each time the charge is shared it halves in value on each sphere;
if F is proportional to the product of the charges then F will be reduced by $\frac{1}{4}$ each time / *OWTTE*; ***[2 max]***
i.e. Look for the halving in value of the charge and the effect is has on F.

(e)



Mark diagram and description together looking for these points:
unlabelled diagram;
description / labeling;
force between the charges produces a twist in suspension;
amount of twist is a measure of the force; ***[4 max]***
*Award good answers **[4 max]** and weak answers **[1 max]**.*

E3. (a) *Any two of:*
radiation is only emitted when the atom (electron) makes a transition from a higher to a lower energy state;
the difference in energy between the two states, $\Delta E = hf$;
the angular momentum of the electron is quantised in units of $\frac{h}{2\pi}$; ***[2 max]***
$\left(mvr = \frac{h}{2\pi} \right)$
*Award **[0]** for orbiting electrons do not radiate (electromagnetic waves).*

(b) in the ground state $n = 1$, so;
$E_1 = -13.6\,\text{eV}$ $r_1 = 0.0529\,\text{nm}$ $v_1 = 2.19 \times 10^6\ \text{m s}^{-1}$; ***[2 max]***
All three must be correct for the second mark. Allow ECF but not if n = 0.

(c) (i) $\Delta x = 0.\ 0529$ nm, hence $\Delta p = \frac{\left(\frac{h}{2\pi}\right)}{0.0529} \times 10^9$;
$= m\ \Delta v$;
hence $\Delta v = \frac{\left(\frac{h}{2\pi}\right)}{0.0529} \times 10^9\ \text{m} = 2.2 \times 10^6\ \text{m s}^{-1}$; ***[3 max]***

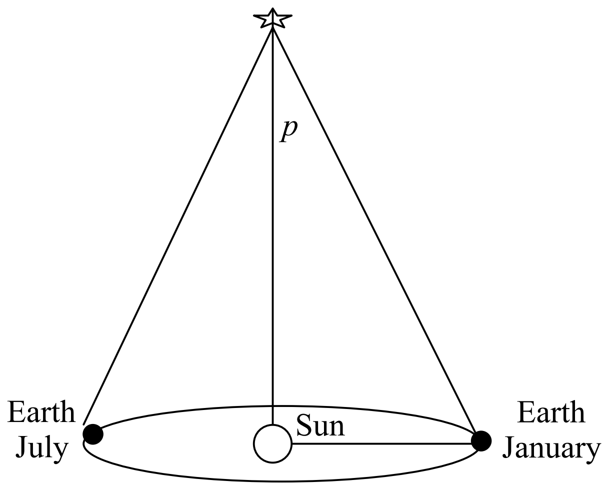
(ii) the bare statement that there is a (relatively) large uncertainty in the position **and/or** the momentum/velocity of the electron;
some discussion that this situation cannot be "improved upon"; *up to **[2]***
e.g. if the position uncertainty is made smaller (to better define the radius), the speed uncertainty gets even bigger and vice versa;
hence the picture of well defined "orbits" is inappropriate / *OWTTE*; ***[3 max]***

OPTION F — ASTROPHYSICS

F1. (a) Earth → Mars → Jupiter → Pluto; ***[2 max]***
*All correct **[2]**, two in the wrong place **[1]**.*

(b) Pluto → Mars → Earth → Jupiter; ***[2 max]***
*All correct **[2]**, two in the wrong place **[1]**.*

F2. (a)



Mark the definition of p and description of its measurement along with the diagram.
Essentially diagram should:
show p;
position of Sun;
position of Earth;
then definition of $p = \dfrac{\text{(distance of Earth from Sun)}}{\text{(distance of star from Sun)}}$;
diagram should show Earth positions separated by about six months;
then description should mention that angle of sight is measured at these two positions such that the difference between these two angles is equal to $2p$; ***[6 max]***
*Award **[6 max]** for a clear description and diagram, **[3]** for an average and **[1]** for some rudimentary idea. Mark diagram and description together.*

(b) $d = \dfrac{1}{p} = \dfrac{1}{0.549} = 1.82\ \text{pc}$;
$= 1.82 \times 3.26 = 5.94\ \text{ly}$; ***[2 max]***

(c) (i) the radiant power from a star;
that is incident per m^2 of the Earth's surface;

Alternatively, define from $b = \dfrac{L}{4\pi d^2}$ *but terms must be defined to obtain the mark.*

definition of L;
definition of d; ***[2 max]***

(ii) $L = 4\pi d^2 b$;

therefore, $\dfrac{L_B}{L_S} = \dfrac{d_B{}^2 b_B}{d_S{}^2 b_S}$;

$d_S = 1\ \text{AU}, d_B = 3.8\times10^5\ \text{AU}$;

therefore, $\dfrac{L_B}{L_S} = (3.8)^2 \times 10^{10} \times 2.6\times10^{-14} = 3.8\times10^{-3}$; ***[4 max]***

Allow any answer between (3.0 and 4.0)$\times 10^{-3}$.

(d) (i) temperature too low for it to be a white dwarf; ***[1 max]***

(ii) luminosity too low for it to be a red giant; ***[1 max]***

F3. (a) fusion;
of hydrogen to form helium; ***[2 max]***
*Responses must have all three aspects correct e.g. "nuclear fusion" would receive **[0]**, "hydrogen forms helium", would receive **[1]**.*

(b) the temperature must be "high enough" is adequate; ***[1 max]***

(c) the stars "run out of" hydrogen (in their cores); ***[1 max]***

(d) *Award **[1]** each for any salient points for the two evolutionary paths post red giant stage. Award **[3]** "per path" up to **[6 max]**. The **Chandrasekhar limit** must be correctly noted in **either** (i) **and/or** (ii) and scores **[1 max]**. Mention must be made of the Chandrasekhar limit to achieve full marks; else award **[1 max]**.*

Note that the information could be presented "pictorially" as stages in the evolutionary progress.

(i) *low mass stars*:
helium fusion in the core pushes out the outer layers of the star to form a planetary nebula;
with a small (collapsed) hot star at its centre – a white dwarf;
mass of the remaining core ≈< Chandrasekhar limit / ≈> $1.4M_{sun}$;
carbon fusion cannot take place;
when helium runs out the star cools;
core cannot collapse further due to "electron degeneracy pressure"; ***[3 max]***

(ii) *high mass stars*:
carbon fusion and fusion of heavier nuclei can take place;
mass of the remaining core > Chandrasekhar limit / $> 1.4M_{sun}$;
the greater mass allows the gravitational attraction to overcome the electron degeneracy pressure;
finally the core collapses giving a supernova and leaving behind;
either a neutron star (when the contraction / collapse is stopped by neutron degeneracy pressure, core mass $\sim\leq 3M_{sun}$) or a black hole; ***[3 max]***

OPTION G — RELATIVITY

G1. (a) (i) *proper length*
the length of an object as measured by an observer at rest with respect to the object / *OWTTE*; ***[1 max]***

(ii) *proper time*
the time interval between two events measured in the reference frame in which the two events occur at the same place; ***[1 max]***

(iii) *inertial observer*
an observer who is in a reference frame that is moving with constant velocity / in a reference frame in which Newton's 1st law is valid; ***[1 max]***

(b) (i) half-life $= \dfrac{1370}{0.95\,c}$;
$= 4.8 \times 10^{-6}$ s; ***[2 max]***

(ii) from $\gamma = \dfrac{1}{\sqrt{1-\dfrac{v^2}{c^2}}}$, $\gamma = 3.2$;

$T = \dfrac{T_0}{\gamma} = 1.5 \times 10^{-6}$ s;

Alternatively, from length contraction $= \dfrac{1370}{3.2} = 430$ m;

half-life of muons $= \dfrac{430}{9.5\,c} = 1.5 \times 10^{-6}$ s; ***[2 max]***

(iii) $L = \dfrac{L_0}{\gamma} = 430$ m; ***[1 max]***

(c) *Mark the answers for* ***time dilation*** *and* ***length contraction*** *together such that a good answer for one can receive* ***[3 max]*** *with* ***[1 max]*** *for the other answer. Answers will be open-ended but look for these main points:*
the muons regarding themselves at rest measure the proper time for half of them to decay;
to the laboratory observers, the muons will take a longer time to decay;
and this is the time that to them, it takes the muons to travel between the counters;
the laboratory observers measure the proper length since the counters are at rest in their reference frame;
to the muons it will seem that counter 2 is travelling towards them;
and in the time that it takes half of them to decay they will measure counter 2 as having travelled a contracted distance 430 m; ***[4 max]***

(d) (i) $m = \dfrac{m_0}{\sqrt{1-\dfrac{v^2}{c^2}}}$ ***or*** $m = \gamma m_0$; ***[1 max]***

(ii) if the muon were to reach the speed of light the bottom line of equation would be zero;
showing that the mass would be infinite. This is clearly not possible; ***[2 max]***
i.e. To receive ***[2]*** *some reference must be made to the equation, otherwise just award* ***[1]****, e.g. "the mass would be infinite".*

(e) (i) $110\,(\pm 10)\ \text{MeV}\,\text{c}^{-2}$; ***[1 max]***

(ii) $340\,(\pm 50)\ \text{MeV}\,\text{c}^{-2}$; ***[1 max]***

(f) $340\,(\pm 50)$ MeV ; ***[1 max]***

(g) $E_{\text{tot}} = Ve + m_0c^2$;
to give $V = 340 - 110 = 230\,(\pm 60)$ MV; ***[2 max]***

G2. (a) (i) Diagram 1: a straight line path (with or without showing the spaceship as having moved); ***[1 max]***

(ii) Diagram 2: a path clearly curving towards the base; ***[1 max]***

Diagram 1: View with respect to the inertial observer

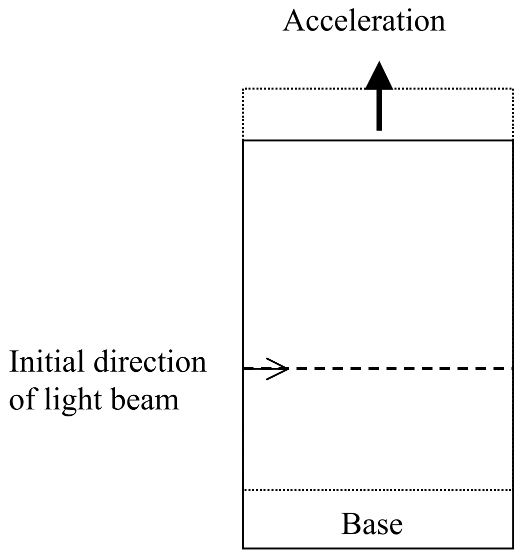
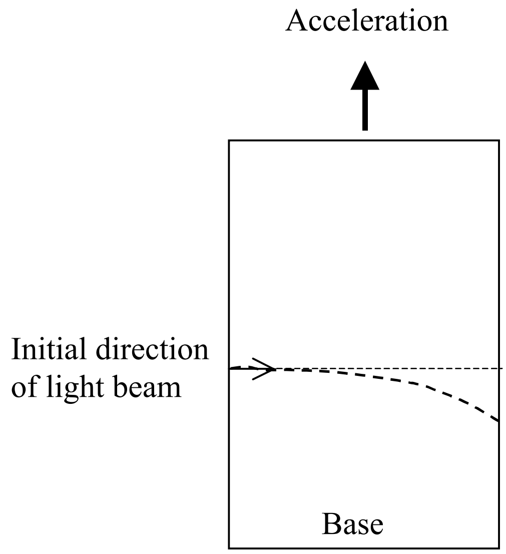


Diagram 2: View with respect to the observer in the spaceship



(iii) *Diagram 1*:
for the inertial observer, the light is travelling in a gravity-free region of space so it would be seen to take a straight-line path / light travels in a straight line in a gravity-free region of space;

Diagram 2:
for the accelerating observer, the spaceship would be displaced in the direction of the acceleration in the time the light takes to go across it;
and in this frame of reference, this displacement is attributed to the beam / *OWTTE*;

An alternative might be:
in both cases the spaceship would be displaced in the direction of the acceleration in the time the light takes to go across it;
(both observers would see the light strike the other side of the spaceship closer to the base);
the observer in the accelerating frame of reference would attribute this to the light beam "bending 'downwards'"; ***[3 max]***

(b) for the observer in the spaceship the constant acceleration (in a gravity-free region of space) is indistinguishable from rest / an inertial frame of reference;
in a uniform gravitational field - which is the equivalence principle / *OWTTE*; ***[2 max]***
*Something like "the observer in the spaceship considers himself to be at rest and would attribute the bending of light to be a gravitational field" would receive **[2]**.*

G3. $E = \gamma mc^2 = 3mc^2$;

$$\Rightarrow \quad \gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = 3 \quad \Rightarrow \quad \frac{v^2}{c^2} = 1 - \frac{1}{9} \,;$$

$$\Rightarrow \quad v = \frac{\sqrt{8}\,c}{3} = 0.94\,c\ (= 2.8\times10^8\ \mathrm{m\,s^{-1}})\,;$$

[3 max]

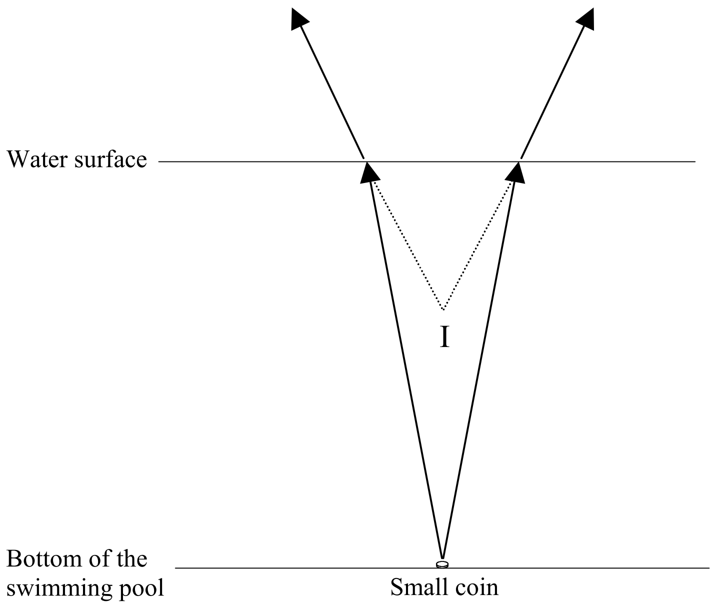
OPTION H — OPTICS

H1. (a) for blue, from the graph $v = 1.9455\ \ (\pm 0.0005) \times 10^{8}\ \mathrm{m\,s^{-1}}$;

$n = \frac{c}{v} = \frac{2.9979}{1.9455} = 1.5409\ \ (\pm\ 0.0005)$; ***[2 max]***

(b) white light contains light of different wavelengths;
each wavelength is deviated by a different amount as it passes through the prism / the refractive index of the prism is dependent on the wavelength / *OWTTE*;
the refractive index is larger for blue light, therefore the refractive angle is smaller;
and so blue light is bent more towards the normal / *OWTTE*; ***[2 max]***
Alternatively, the response may use the aid of a diagram.

H2. (a)



two rays from the coin showing refraction into the air;
extrapolated back to locate the labelled image **I**; ***[2 max]***

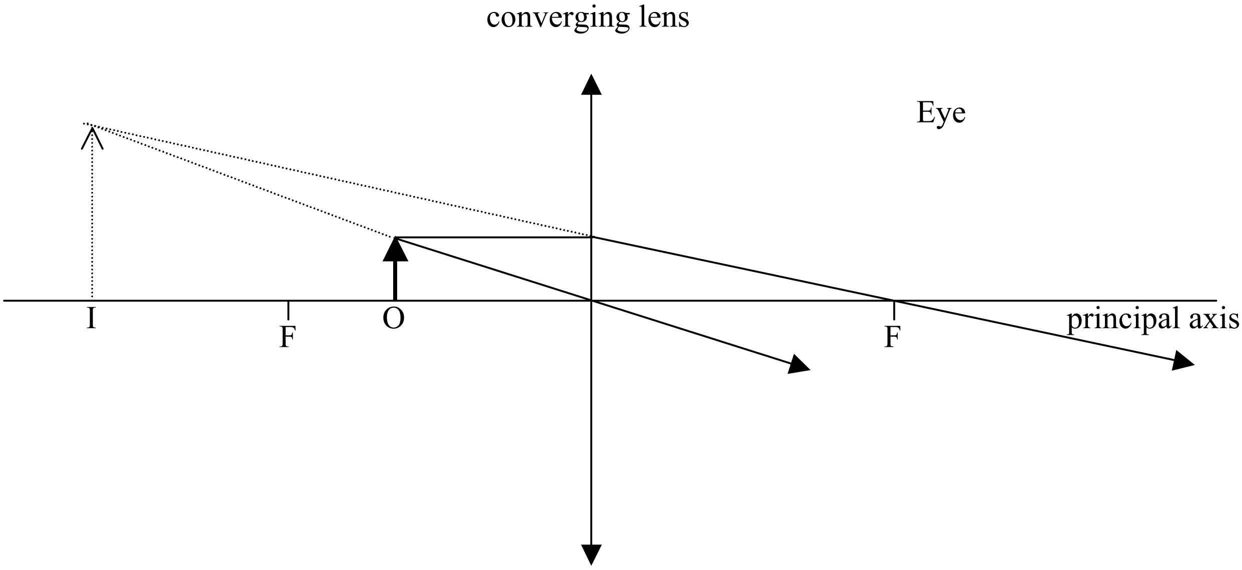
(b) virtual, since the rays form the coin to not come to a focus / *OWTTE*; ***[1 max]***
*Correct answer with wrong or weak or no explanation would receive **[0]**.*

(c) $a = \frac{d}{n}$;

$= \frac{3.0}{1.3} = 2.3\ \mathrm{m}$;

distance from bottom of pool $= 0.7$ m; ***[3 max]***

H3. (a)



(i) two appropriate rays; ***[1 max]***

(ii) correct image position; ***[1 max]***

(iii) eye to the right of the lens; ***[1 max]***

(b) (i) if the object is nearer than this to the eye then the eye cannot focus it clearly / *OWTTE*; ***[1 max]***

(ii) $\frac{1}{u} = -\frac{1}{v} + \frac{1}{f}$;

$v = -(25 - 3)\text{ cm} = -22\text{ cm}$;

$\frac{1}{u} = \frac{1}{22} + \frac{1}{10}$;

to give $u = 6.9$ cm; ***[4 max]***

Alternatively for scale drawing award ***[1]*** *for scale,* ***[2]*** *for rays,* ***[1]*** *for position of image and* ***[1]*** *for subtraction.*

(iii) at the focal point;
the far point is at infinity; ***[2 max]***

H4. (a) interference; ***[1 max]***
Award no marks for "diffraction".

(b) (i) *n* is the refractive index of the oil;
the wavelength in the medium is reduced / depends on *n*; ***[2 max]***

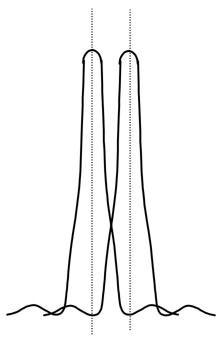
(ii) $t = \frac{650}{(4 \times 1.45)} = 110\ \text{nm}$; ***[1 max]***
*Award **[0]** for use of incorrect refractive index.*

(iii) *Weak answer giving some indication.*
that the rays reflected off the bottom of the oil film now shift / change in phase by $\frac{\lambda}{2}(\pi)$;

A better defined statement.
that initially the rays reflected off the bottom of the oil film (on water), did not suffer a phase change;
but now do shift in phase by $\frac{\lambda}{2}(\pi)$; ***[2 max]***

H5. (a) diffraction / bending of waves (due to an aperture / obstacle); ***[1 max]***

(b) the Rayleigh Criterion is used to establish when the images of two objects are just resolved;
the minimum of one diffraction pattern falls on the maximum of the other;
relevant diagram; ***[3 max]***



Minimum of one diffraction pattern falls on the maximum of the other.

*Note that a well labelled and annotated diagram could receive up to **[2 max]**.*