M01/430/H(3)M

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PHYSICS

Higher Level

Paper 3

20 pages

OPTION D – BIOMEDICAL PHYSICS

D1. (a) systolic: maximum blood pressure produced by a heartbeat; ***[1]***
diastolic: the pressure when the heart relaxes between beats; ***[1]***
*(award **[1]** for just maximum and minimum. For **[2]** some reference should be made to the heart beating. Something like 'the pressure of the blood leaving the heart and the pressure of the blood returning to the heart' would be OK;)*
[2 max]

(b) recognise that $p = \rho g h$; ***[1]***
correct substitution to give 1.1×10^4 Pa; ***[1]***
[2 max]

(c) the upper arm is at nearly the same level as the heart; ***[1]***
hence hydrostatic pressure will not effect the reading; ***[1]***
i.e. the reading will be equal to that of the pressure at the heart;
[2 max]

(d) estimated height of aorta above the ankle = 1.2 m (allow 1 m to 1.6 m); ***[1]***
hydrostatic pressure difference $\Delta p = 1000 \times 10 \times 1.2$ Pa = 90 mm of Hg; ***[1]***
pressure reading at ankle = 90 + 140 = 230 mm of Hg (138 to 254); ***[1]***
answer in kPa acceptable = 32 kPa (19 to 35);
assumptions: ignore any pressure drops due to fluid flow resistance; ***[1]***
assume blood has same density as water; ***[1]***
[4 max]

D2. (a) energy loss is proportional to surface area; ***[1]***
mass is proportional to volume; ***[1]***

$$\frac{M_{toby}}{M_{susie}} = \frac{7}{5} = \frac{(1_{toby})^3}{(1_{susie})^3};$$ ***[1]***

$$\frac{1_{toby}{}^2}{1_{susie}{}^2} = \left(\frac{7}{5}\right)^{\frac{2}{3}} = 1.25;$$ ***[1]***

*(accept Susie to Toby = 0.8 but deduct **[1]** if this is not made clear;)*
[4 max]

(b) *any sensible assumption;*
e.g. same build *i.e.* same overall shape, identical clothing; ***[1 max]***

D3. (a) use $\beta = 10 \log \frac{I}{10^{-12}}$ to show that 10^{-8} W m^{-2} = 40 dB; ***[1]***
from the graph frequency range = 50 → 10 000 (±1 000)Hz; ***[1]***
[2 max]

(b) minimum of the graph at about 1500 Hz (±500)Hz; ***[1 max]***

(c) 200 Hz is at about 10 dB, 10 000 at 40 dB; ***[1]***
$40 \text{ dB} = 10^{-8}$ W m^{-2}, $10 \text{ dB} = 10^{-11}$ W m^{-2}
therefore 200 Hz must be 1 000× less intense; ***[1]***
*(allow **[1]** if answer is 4×)*
[2 max]

D4. (a) *any two of:* ***[1]*** *plus* ***[1]***
scattering (elastic collisions);
photoelectric effect (inelastic collisions);
compton effect;
pair production;
[2 max]

(b) define from $I = I_o e^{-\mu x}$; ***[1]***
I_0 = incident intensity of the X-rays on the absorbing material;
I = intensity after the beam has travelled distance x through the material; ***[1]***
(i.e. the equation on its own is worth nothing unless they show that they understand the terms and what is going on)
[2 max]

(c) the energy of the x-rays (photons); ***[1]***
the nature of the material (Z); ***[1]***
[2 max]

(d) use $I = I_o e^{-\mu x}$; ***[1]***
to give $I_{bone} = I_0 \mathrm{e}^{-60\times0.05} = 0.05 I_0$ and $I_{tissue} = I_0 e^{-5\times0.10} = 0.50 I_0$; ***[1]***
such that $\frac{I_{bone}}{I_{tissue}} = 0.8 = \frac{1}{12}$; ***[1]***
[max 3]

(e) the bone will absorb most of photons of this energy whereas the tissue absorbs few so producing good contrast on the x-ray film; ***[1 max]***
(or words to the effect that there will be a good contrast between tissue and bone image;)

OPTION E – HISTORICAL PHYSICS

E1. (a)

Aspect of the observations	***Aristotle's view***	***Galileo's view***
The time for books of different mass to reach the ground when dropped from the same height.	Heavier objects reach the ground first *(or fall faster)*;	All objects will reach the ground at the same time;
The relationship between a constant force applied to a book and the velocity of the book.	A constant force produces constant velocity;	A constant force produces a constant acceleration (constant changing velocity);

[1]** for each correct answer;* ***[4 max]

(b) Aristotle just assumed *(or reached his conclusion by thinking)* whereas Galileo carried out measurements *(or verified his views experimentally or by observation)*; ***[1 max]***

(c) Newton proposed that the rate of change of momentum of the book is equal to the force *(accept Force = mass $\times$ acceleration)*; ***[1 max]***

E2. (a) Tycho de Brahe; ***[1 max]***

(b) because the planets actually have elliptical orbits; ***[1 max]***

(c) recognise that the orbital period of the Earth is 1 year; ***[1]***
use Kepler's 3rd law $T^2 \propto R^3$; ***[1]***
to give 5.2 years; ***[1]***
[3 max]

(d) (i) that the force acts along a line joining the centre of the planets; ***[1 max]***

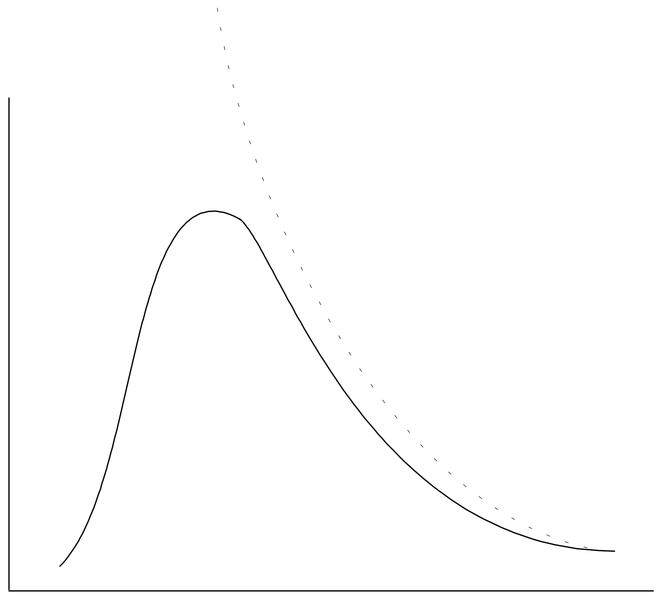
(ii) that the planet acts as a particle; ***[1]***
equal in mass to the planet; ***[1]***
or something to the effect that the mass of the planet acts as though it were concentrated at the centre of the planet.
[2 max]

(iii) use $\frac{mv^2}{R} = \frac{GMm}{R^2}$; ***[1]***
to give $\frac{T^2}{R^3} = \frac{4\pi^2}{GM}$; ***[1]***
from which $M = \frac{4\pi^2 R^3}{T^2 G}$; ***[1]***
correct substitution to get $M \approx 3 \times 10^{30}$ kg; ***[1]***
[4 max]

(iv) look for an answer along the lines that if the position and velocity of all the particles in a system are known at some instant then it is possible to predict all future configurations of the system;

*they will probably quote the universe as the system and that is fine. Use your discretion - if they have got the idea then award **[2]**;*
[2 max]

E3. (a)



dotted curve *(look for the bit going to infinity)*; ***[1 max]***

(b) although R-J fits agrees well at low frequencies; ***[1]***
the intensity heads for infinity as the wavelength gets smaller; ***[1]***
or
since the intensity heads for infinity in the ultraviolet region**;** ***[1]***
a catastrophe since this means that the theory is wrong; ***[1]***
(other answers are possible - students might argue that from a classical point of view, as the electrons emit radiation they spiral into the nucleus and move faster and faster, emitting shorter and shorter wavelengths until the finally collapse into the nucleus;)
[2 max]

(c) R-J ***[1]***
radiation emitted and absorbed continuously;
intensity depends on the amplitude ***[1]*** of the atomic oscillators ***[1]***; ***[2]***
P
energy of the oscillators is quantised; ***[1]***
energy per bundle is proportional to frequency; ***[1]***

(either emitted or absorbed is OK - no need for both and atomic oscillators (atoms) need only be mentioned the once);
[5 max]

(d) Planck's model gives a result that agrees with experiment; ***[1 max]***

(e) that the emitted radiation continued to exist as a bundle or packet; ***[1 max]***

OPTION F – ASTROPHYSICS

F1. (a)

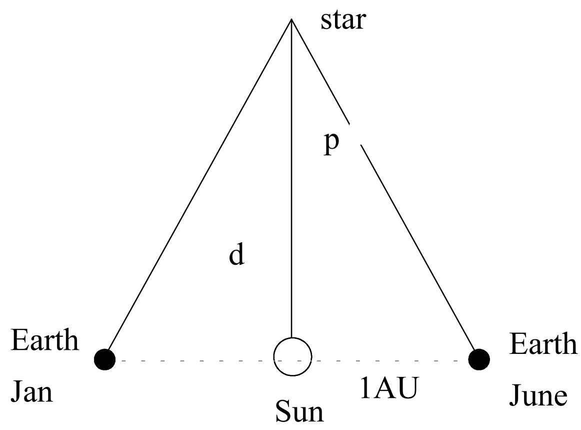


diagram:
position of Sun and star; ***[1]***
1 AU; ***[1]***
Earth in two positions separated by 6 months; ***[1]***

description:
measure angular position of star at two positions separated by 6 months; ***[1]***
to find angle p; ***[1]***
$d = \frac{1}{p}$; ***[1]***

[max 6]

*although the scheme shows a split of **[3]** + **[3]** between diagram and explanation do not be too rigorous about this - essentially look for a good description of parallax bearing in mind the points mentioned in the scheme;*

(b) (i) Sirius has a shorter wavelength maximum; ***[1]***
and is therefore hotter than the Sun; ***[1]***
[2 max]

(ii) use $\frac{\lambda_{sun}}{\lambda_{sirius}} = \frac{T_{sirius}}{T_{sun}}$ or $\lambda_{\max} = \frac{2.9\times10^{-3}}{T}$; ***[1]***

($\lambda_{\text{sun}} = 480$ nm, $\lambda_{\text{sirus}} = 280$ nm);

to give $T_{sirius} = 10\,000$ K (± 500 K); ***[1]***
[2 max]

(c) distance $= 2.64 \times 2.1 \times 10^5 = 5.5 \times 10^5$ AU; ***[max 1]***

(d) use $L = 4\pi d^2 b$; ***[1]***

to give $\frac{L_{sun}}{L_{sirius}} = \frac{d_{sun}{}^2 b_{sun}}{d_{sirius}{}^2 b_{sirius}}$; ***[2]***

to give $L_{sirius} = 3.1 \times 10^3 L_{sun}$; ***[1]***

(i.e. ***[3]*** *for sorting out the right equation to use and transforming it appropriately and* ***[1]*** *for the arithmetic;)*

[4 max]

(e) accept *either* radius *or* surface area (*or* size); ***[1 max]***

(f) (i) *any two (****[1]*** *for each) sensible differences e.g.* White dwarf;
has smaller radius;
more dense;
higher surface temperature;
energy not produced by nuclear fusion;

[2 max]

(iii) *look for these main points;*
hydrogen fusion in the core ceases when all the hydrogen has been used up;
the core contracts and the outer layers expand;
hydrogen fusion takes place in the outer layers and the star becomes a red giant;
as the core continues to contract helium fusion takes place in the outer layers;
the star ejects matter into space in the form of a planetary nebula;
when all the hydrogen and helium is used up all that remains is the very hot core;

the process is actually more complicated than this. Essentially award up to ***[6]*** *for a good answer. An answer that just mentions contraction of the core, expansion to a red giant and something like outer layers blown away to leave the core would be* ***[3]*** *out of* ***[6]****;*

[6 max]

(g) *look for these main points;*
the star becomes a super-red giant;
fusion of elements such as Oxygen and Silicon takes place in the outer layers;
the outer layers become unstable and explode away from the core as a supernova;
the core further collapses to a neutron star (or black hole);

*again the process is complicated and theoretical at best So look for salient points as above. Answers that just mention super-red giant and neutron star award **[2]** out of **[4]**;*

[4 max]

(h) (i) the two stars can actually be observed as single, separate stars; ***[1 max]***
(any simple answer like this will suffice that shows that the candidates realise that the two stars can actually be observed;)

(ii) the orbital period of the two stars (or just period of orbit will do); ***[1 max]***

OPTION G – SPECIAL AND GENERAL RELATIVITY

Gl. (a) (i) a reference frame that is moving with constant velocity;
(or uniform speed in a straight line); ***[1 max]***

(ii) all inertial observers; ***[1]***
will measure the same value for the speed of light; ***[1]***
*(i.e. only **[1]** if inertial observers are not mentioned;)*
[2 max]

(b) (i) $\frac{v\Delta t}{2}$; ***[1 max]***

(ii) $\frac{c\Delta t}{2}$; ***[1 max]***

(c) (i) $\frac{c\Delta t^{/}}{2}$; ***[1 max]***

(ii) recognise that Pythagoras' theorem is used; ***[1]***
to give $c^2\Delta t^2 = v^2\Delta t^2 + c^2\Delta t^{/2}$; ***[1]***
rearrange to give $\Delta t = \gamma\Delta t^{/}$; ***[2]***
*(if they get bogged down in the rearranging allow **[2]** or **[3]** depending on how far they get;)*
[4 max]

(d) (i) γ= 2.3; ***[1]***
therefore 2.3 revolutions; ***[1]***
[2 max]

(e) (i) *look for an answer that mentions the following points:*
their short half-life means that most of them should decay before reaching the surface of the Earth; ***[1]***
however, a significant number of muons are detected at the surface of the Earth; ***[1]***
because of the high speed of the muons; ***[1]***
relative to an Earth observer the half-life of the muons will be longer and so they have sufficient time to reach the Earth; ***[1]***
*(use your judgement i.e. good idea of what's happening **[4]** some idea **[2]**;)*

[4 max]

(ii) recognise that $\gamma = 2.3$; ***[1]***
so that half-life as measured by laboratory observer = 7.1×10^{-6} s; ***[1]***
therefore distance travelled = $0.9c \times 7.1 \times 10^{-6} = 1920$ m; ***[1]***
[max 3]

G2. (a) 50 MeV; ***[1 max]***

(b) $\gamma = \left(1 - \frac{v^2}{c^2}\right)^{-½}$; ***[1]***

to give $\gamma = 1.5$; ***[1]***
KE $= (\gamma - 1)m_0 c^2$; ***[1]***
to give $m_0 \approx 100$ MeV/c^2; ***[1]***
[4 max]

(c) total mass $= \frac{150}{c^2}$MeV; ***[1]***

$p = mv = \frac{150}{c^2} \times 0.75c \approx 113$ MeV/c; ***[1]***

*(if they just multiply 150 and 0.75, award **[1]** i.e. for **[2]** they must show that they know what the mass is;)* ***[max 2]***

G3. *answers will be open-ended but look for something along these lines:*
the acceleration of an object by a given force is inversely proportional to the objects inertial mass; ***[1]***
the gravitational force on an object is proportional to the gravitational mass of the object; ***[1]***
if objects accelerated by a gravitational force have the same acceleration it follows that $m_g = m_i$; ***[2]***

or a mathematical argument might be given

$F_G = km_G$; ***[1]***
$F_G = m_I a$; ***[1]***
therefore $a = k\frac{m_G}{m_I} = $ k; ***[1]***
if $m_G = m_I$; ***[1]***

*(essentially any verbal argument should be a summary of the above mathematical argument. If they know the difference between inertial and gravitational mass but can't get any further then **[1]** out of **[4]**;)*

[4 max]

OPTION H – OPTICS

H1. (a)

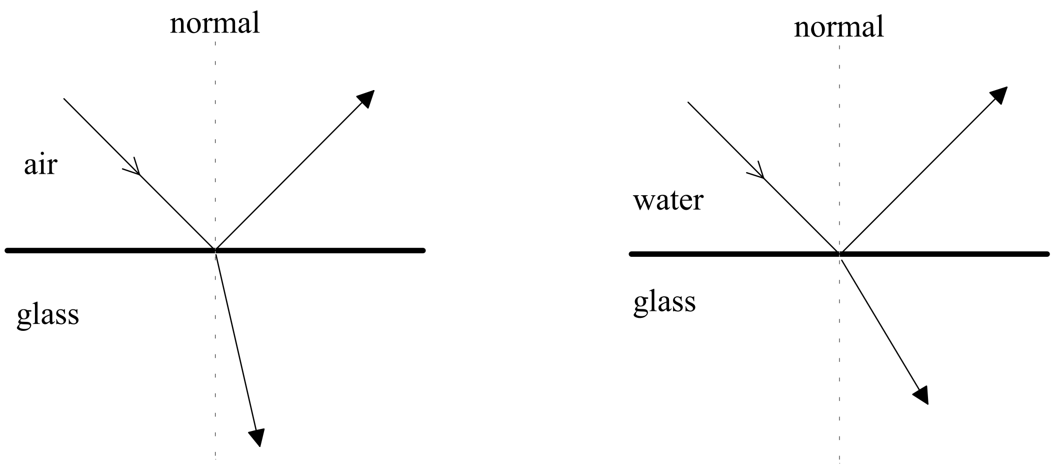


Diagram 1 **Diagram 2**

reflected rays; *[1]*
refraction of the rays; *[1]*
much less refraction in diagram 2; *[1]*
[3 max]

(b) $\phi_c = \sin^{-1}\left(\frac{1.3}{1.5}\right) = 60^\circ$ ***[1 max]***

(c)

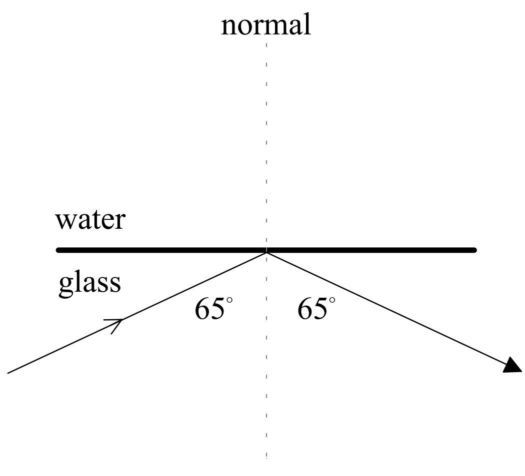
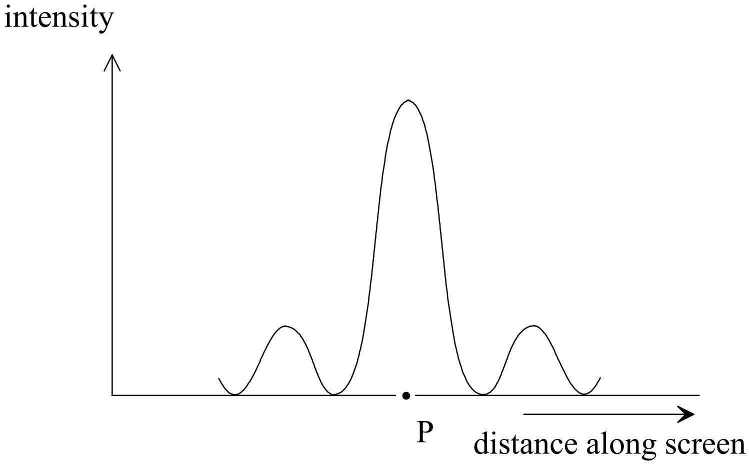


diagram to show total internal reflection; *[1]*
reflected angle looking equal to incident angle; *[1]*
[2 max]

(d) calculation of $\phi_c = \sin^{-1}\left(\frac{1.54}{1.55}\right) = 83^\circ$; *[1]*

if a ray crosses the boundary at 8° it will be incident on the boundary at 82° this is less than ϕ_c hence ray will not be internally reflected; *[1]*
[2 max]

H2. (i)



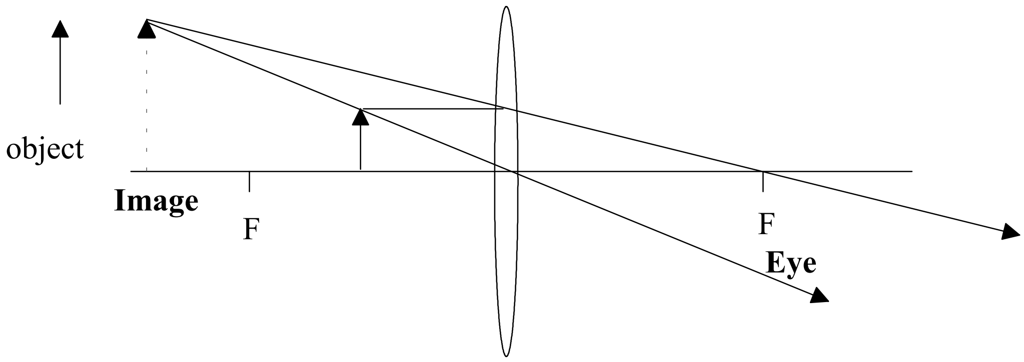
overall shape; ***[1]***
correct position of central maximum; ***[1]***
secondary maxima significantly smaller than principal maximum; ***[1]***
(should be $\frac{1}{9}$ the size but don't look for this accuracy or accuracy in the relative widths of the maxima - the above diagram certainly isn't!)

[3 max]

(b) $\theta = \frac{\lambda}{b} = \frac{d}{D}$ (b = slit width, d = half-width of central maximum, D = distance from slit to screen); ***[1]***
correct substitution to give d = 5 mm; ***[1]***
therefore width of central maximum = 10 mm; ***[1]***

[3 max]

H3. (a)

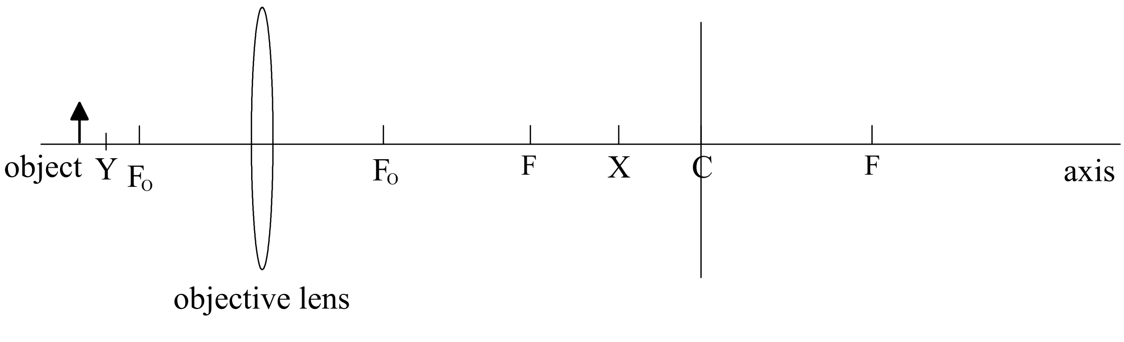


(i) object between F and centre of curvature of the lens; ***[1 max]***

(ii) the two appropriate rays; ***[1]***
position of image; ***[1]***
[2 max]

(iii) position of eye (anywhere on the side of the lens opposite to the object); ***[1 max]***

(b)



(i)→(iv) ***[1]*** for each correct position. The F to the left of the eyepiece is the important one. The other important thing to look for is that the image formed by the objective is within the PF of the eyepiece; ***[4 max]***

H4. (a) (i) *answers will be open-ended so look for these main points:*
when light from each star enters the eye it is diffracted; ***[1]***
the light forms a diffraction pattern on the retina; ***[1]***
if the maximum of each star's diffraction pattern overlap then the stars will appear as a single blob *(accept point)*; ***[1]***

[max 3]

(ii) Rayleigh's criterion states that the two stars will be resolved if the angle that they subtend at the eye $=1.22\frac{\lambda}{b}$ where b is the diameter of the eye; ***[1]***
the telescope objective has a much greater diameter than the eye and so the Rayleigh criterion will be satisfied; ***[1]***
(note that the Raleigh criterion need not be mentioned by name or explicitly stated. This part of answer could be given solely in terms of something 'like as b increases the angular width of the maxima decreases and so the maxima become separated');

[2 max]

(b) recognise that $\theta = 1.22\frac{\lambda}{b}$; ***[1]***

$\theta = \frac{2.6 \times 10^{11}}{4.2 \times 10^{16}} = 6.2 \times 10^{-6}$; ***[1]***

numbers in the right place, $6.2\times10^{-6} = \frac{1.22 \times 1 \times 5 \times 10^{-7}}{b}$
to give $b = 10$ cm (9.8 cm); ***[1]***
(do not penalise if the 1.22 is missed out; answer 8.1 cm)

[3 max]