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MARKSCHEME

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PHYSICS

Higher Level

Paper 3

21 pages

OPTION D — BIOMEDICAL PHYSICS

D1. (a) Heat loss = $H_{loss} \sim$ (surface) area $\sim L^2$ *[1]*
So, H_{loss} (Youlie) $\sim 0.7^2$ H_{loss} (father) = 0.5 H_{loss} (father) *[1]*
[Assumes all else is 'equal'].

[max 2 marks]

(b) Survival depends on rate of heat generation, H_{gen}, compared to rate of heat loss. *[1]*
$H_{gen} \sim$ volume $\sim L^3$ *[1]*
Hence, H_{gen} (Youlie) $\sim 0.7^3$ H_{gen} (father) = 0.34 H_{gen} (father) *[1]*
So Youlie losses heat relatively faster than she generates it ⇒ QED *[1]*
OR
Ratio (H_{gen}/H_{loss}) (Youlie) $\sim$ 0.7(H_{gen}/H_{loss}) (father). *[1]*
(ECF from (a))
[Accept a non-quantitative answer as long as physical principles are discussed]

[max 4 marks]

D2. (a) *Any two of the following:*
the blood flow must be laminar/ streamlined/ not turbulent;
blood is incompressible;
viscosity is constant;
pulsing of the heart leads to expanding and contracting of arteries;
⇒ variable R / cross-sectional area ***[max 2 marks]***

(b) Blood flow rates (seriously) decreased by thickening; *[1]*
Blood pressure goes up with thickening, to try and maintain blood flow (heart must work harder); *[1]*
Control of blood flow rates
reduced by hardening and thickening *[1]*
muscle bands around arteries must work harder to make changes to R *[1]*
Reference to $Q \sim R^4 \Delta P$ *[1]*

[max 5 marks]

D3. (a) Subject listens to discrete test frequencies (one ear at a time) *[1]*
Sound intensity is raised until subject reports (barely) discerning it *[1]*
Sound intensity compared to 'normal' hearing: 0 dB *[1]*
Other stuff is also acceptable *e.g.* the process is subjective

[max 3 marks]

(b) (i) Presbycusis (hearing loss due to old age) – B *[1]*
– general, increasing decline at high frequencies *[1]*

(ii) Otosclerosis (a form of conductive hearing loss) – C *[1]*
– broad-band/ uniform loss with frequency *[1]*

(iii) Hearing loss associated with noise exposure must then be – A (although B is also acceptable)
– localised dip (or broad high frequency damage) *[1]*

[max 5 marks]

D4. (a) What? A radioactive nuclide (emitting γ or high energy β) (in chemical combination) whose location in the body can be found / that can be traced. *[1]*

Why? *Any one of:*
can follow (biological) processes/ reactions;
detect 'blockages'/ unusual concentrations; other.... *[1]*

[max 2 marks]

(b) Looking for gamma sources (for best detection) and an appropriate half-life. *[1]*
^{223}Fr: eliminated: α & β emitter (nasty in the body) and/ or half-life too short. *[1]*
^{90}Sr: eliminated: NOT γ and/ accumulates in the body (nasty) / accept half-life too long
($\Rightarrow$ larger doses for viable measurements) *[1]*
^{99}Tc: OK.
*[If just (guess?) ^{99}Tc pay **[1 mark]** only (generous!)]*

[max 3 marks]

(c) (i) It is the time for half of the radionuclide to be removed from the body *[1]*
by natural processes (any one of – sweat/ wastes; breathing, *etc.*) *[1]*

[max 2 marks]

(ii) 24 hr is 1 bio. half-life $\Rightarrow \frac{1}{2}$ of the material left
and 2 radio half-lives $\Rightarrow \frac{1}{4}$ of the material left *[1]* for either **or both**

so amount of the material left = $\frac{1}{8}$ *[1]*

*[So, if one half-life only is correct, they score **[1mark]**]* ***[max 2 marks]***

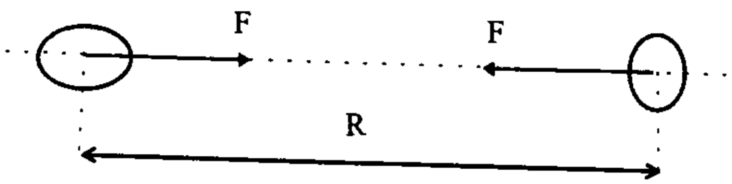
OPTION E — HISTORICAL PHYSICS

E1. (a) (Euclidean) geometry *[max 1 mark]*

(b) ALL matter attracts ALL matter. *[1]*
The gravitational force extends beyond the 'Earth's sphere' / throughout the universe. *[1]*
[max 2 marks]

(c) Central force: acts along the 'line of centres' of interacting bodies. *[1]*
Inverse square law: is proportional to $1/R^2$, with R the distance between centres. *[1]*

OR a diagram (of course):



and $F \propto 1/R^2$

[max 2 marks]

(d) (i) Acceleration due to gravity at the Moon's orbit $= 9.81 \times (6.37 \times 10^6 / 3.84 \times 10^8)^2$ *[1]*
$= 9.81 \times (1/60)^2 = 0.0027\ \text{ms}^{-2}$ *[1]*
[max 2 marks]

(ii) Centripetal acceleration required $= v^2/R = (2\pi R/T)^2\,(1/R)$ *[1]*
$= 4\pi^2 R/T^2$
$= 4\pi^2 \times 3.84 \times 10^8 / (27.3 \times 24 \times 3600)^2$ *[1]*
$= 0.0027\ \text{ms}^{-2}$ *[1]*
[max 3 marks]

(iii) They should be equal. *[max 1 mark]*

[This has even more value if there has been a numerical error made and the two calculated results appear as NOT equal!]

E2. (a) Note that this question is NOT about 'what is the mechanical equivalent of heat'!

Mayer's result would be inaccurate by the amount that 4186 J differs from $mgh = 1 \times 9.8 \times 365 = 3580$ J *[1]*

$\Rightarrow$ % error = $(4186 - 3580) \times 100 / 4186 = 14.5$ % *[1]*

[max 2 marks]

(b) (i) Conservation of Energy ***[max 1 mark]***

(ii) Joule conducted a number of different experiments (including electrical) and any one of these would suffice, but his most famous (which will presumably be the most common answer) was the 'paddle wheels in water' experiment. He made all sorts, including 'single' and 'double sided' arrangements.

Reasonable <u>sketch</u> conveying main idea. *[1]*

2 - 3 labels for important features *[1]*
(thermal insulation/ calorimeter, masses/ weights, water (?!), thermometer)

More labels/ details *[1]*
Needed to measure: <u>distance</u> masses fall through and <u>temperature</u> increase **need both** for ***[1 mark]***
*[Hammer and lead sheet gets only **[1 mark]**]*

[max 4 marks]

(iii) Minimise:
Heat losses from the water $\Rightarrow$ heat losses reduce temperature increase *[1] + [1]*
Frictional losses $\Rightarrow$ reduce temperature increase *[1] + [1]*
Also acceptable
Kinetic energy of falling masses
$\Rightarrow$ significant KE reduces temperature increase *[1] + [1]*
BUT
Uncertainties in the height through which the masses fall (would be negligible) ***[1 mark]*** only

[max 4 marks]

E3. (a) udd *[any THREE gets **[1mark]**]* ***[max 2 marks]***

(b) (i) The Weak Interaction ***[max 1 mark]***

(ii) Charge = –1; Baryon No = 0; Lepton No = 0. ***[1 mark]*** for each ***[max 3 marks]***

(iii) Proton structure is uud, *[1]*
so a d quark was transformed into an u quark (plus the W^-) *[1]*

[max 2 marks]

OPTION F — ASTROPHYSICS

F1. (a)

Red giant	[3]	Galaxy	[5]
Jupiter	[2]	Neutron star	[1]
Solar system	[4]		

One correct = *[0]*
Two correct = *[1]*
Three correct = *[2]*
Four (and therefore five) correct = *[3]*
[max 3 marks]

(b) (i) Its mass ***[max 1 mark]***

(ii) In the red giant stage He 'burning' quickly goes to C and O burning. *[1]*
[This is very fast (& happens (in layers/ shells)] and blows off the outer layers forming planetary nebulas and *[1]*
leaving a bright central core which slowly cools down. *[1]*
It will become a white dwarf. *[1]*
[All stars with a mass < 1.4 solar masses become white dwarfs.]

[max 4 marks]

F2. (a) Origin: absorption of parts of the emitted continuous spectrum by the outer atmospheres of stars *[1]*

What? composition *[1]*
of stars *[1]*

Also, intensities give details of star class
[Accept velocity, elements or compounds]

[max 3 marks]

(b) (i) Due to a relative velocity between the star and Earth. *[1]*
*Plus **one** item of other related information:* *[1]*
The Doppler Effect as applied to electromagnetic radiation
Can be a decrease or increase in λ.
The *[radial component]* of the relative velocity of star and Earth can be determined.
[This mark can also be awarded for info. given explicitly or implicitly in (ii), below]

[max 2 marks]

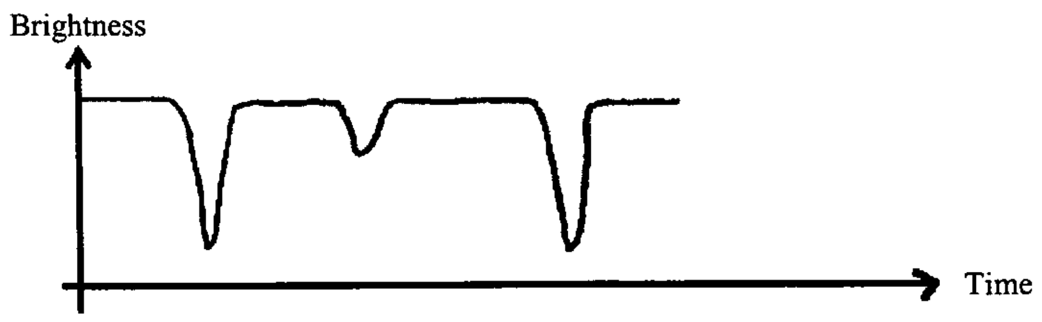
(ii) *[Mark this in conjunction with (i) above.]*
To gain a mark here, between the two answers (to (b) (i) & (ii)) it should be clear that the radial component of the relative velocity of star and Earth can be determined. *[1]*

$\Delta\lambda$ is sufficiently small that the 'small shift' formula can be used: $\Delta\lambda/\lambda \approx v/c$ *[1]*
$\Rightarrow v \approx 0.030\ c$ *[1]*
$= 9 \times 10^6\ ms^{-1}$ *[1]*

[max 4 marks]

[Candidates can of course use the exact form $\Rightarrow 1.03 = \sqrt{(1 + v/c) / (1 - v/c)}$ *[1]*
Lots of algebra: $1.03^2 (1 - v/c) = (1 + v/c)$ $\Rightarrow 0.609 = 2.61 (v/c)$ *[1]*
$\Rightarrow v = 0.02955c = 0.030c$*]* *[1]*

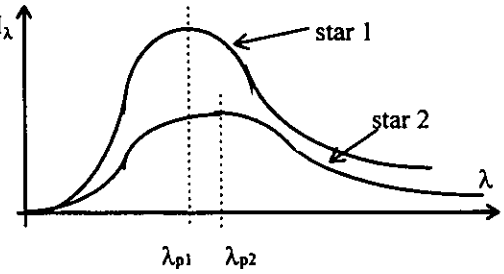
(c) *For [2 marks], no great detail is required. [2 marks] for either of:*
Variable Doppler shift in the spectrum *[2]*
OR
Periodically varying brightness/ light curve *[1]*
due to eclipsing *[1]*
OR a diagram! *[2 marks]*



[max 2 marks]

F3. (a) λ_p is the maximum in the 'spectral intensity' *[1]*
$T_1 > T_2 \Rightarrow \lambda_{p1} < \lambda_{p2}$ *[1]*

Diagram *[1]*



(A good, well labelled diagram can gain ***[3 marks]*** but the temperatures must somehow be stated.)

[max 3 marks]

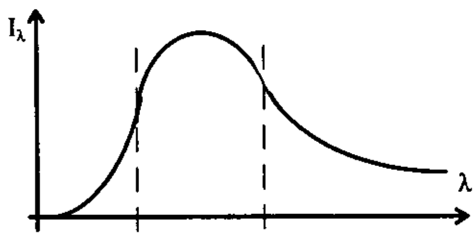
(b) $\lambda_P = 2.90 \times 10^{-3} / T = 2.90 \times 10^{-3} / 3 = 1 \times 10^{-3}$m. *[1]*

Spectral region	microwave	*[1]*
Telescope	radio telescope	*[1]*

[max 3 marks]

(c) Confirmed the 'big-bang' hypothesis for the origin of the universe AND *[1]*
the subsequent expansion. *[1]*

[max 2 marks]



(d) Need relative intensity measurements at, at least, two wavelengths in order to obtain a temperature. (Preferably on either side of the peak in the spectral intensity curve, I_λ).

[Accept that all wavelengths near the peak need to be measured in order to establish its position]

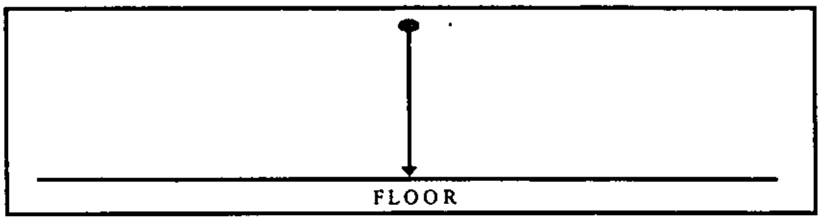
[max 2 marks]

(e) The spectral intensity peak will continue to move to greater wavelengths / lower temperatures / lower energies. *[1]*

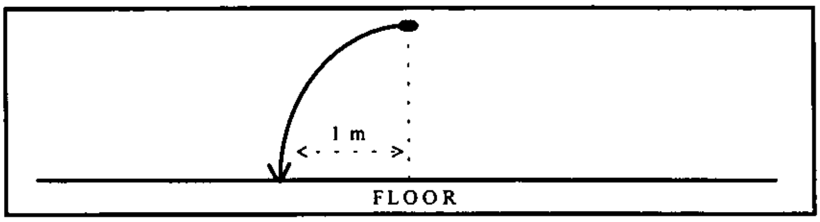
OPTION G — SPECIAL AND GENERAL RELATIVITY

G1. (a) ***[1 mark]*** per correct diagram (general shape/ direction) plus
[1 mark] for correct 1 m AND 3 m horizontal displacement.

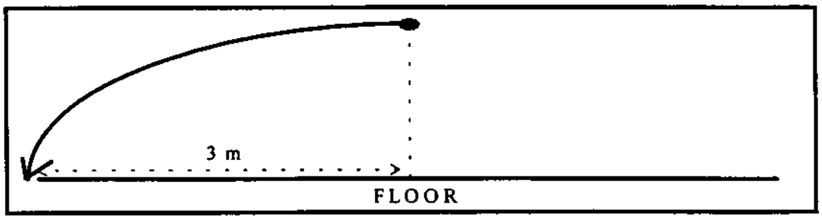
with respect to observer A



with respect to observer B



with respect to observer C



[max 4 marks]

(b) $^{V}{}_{B\,rel\,A}$ = +0.40c (to 'the right') – by 'inspection' ***[1]***

$^{V}{}_{C\,rel\,A}$ = $u_x' = (u_x - v) / (1 - u_x v/c^2)$ ***[1]***

[This identifies B with Frame of Ref. 'S' and A with S']
[The same, with all + signs is acceptable]

$= [+0.8 - (-0.4)]c / [1 - 0.8\,(-0.4)] = 0.91c$ ***[1]***

Positive result (velocity to 'the right') ***[1]***
*[If the calculation is wrong, but there is a clear realisation (implicit or explicit) that the result must be > 0.80c and < c, pay **[1 mark]**]*

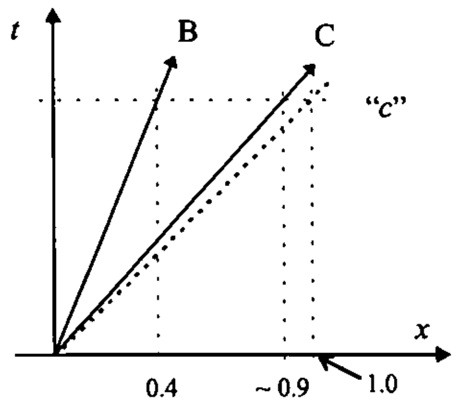
[max 4 marks]

(c) $\Delta t_B = \gamma \Delta t_A$ ***[1]***
with $\gamma = 1 / \sqrt{(1 - (0.4c/c)^2)} = 1 / \sqrt{(1 - 0.16)} = 1.09$ ***[1]***

$\Delta t_B = 1.09 \times 0.5 = 0.545$ s ***[1]***
*[If reference systems are confused ($t_B = t_A/\gamma$) award **[1 mark]**]*

[max 3 marks]

(d) This question calls for a sketch, however B should have a gradient ≈ 0.4 'c' *[1]*
and
C should have a gradient > 0.8 and < 'c'. *[1]*
<u>Both</u> should have 'positive speeds' *[1]*
*[If the world lines of B and C are on the other side of 'c' but otherwise correct award **[3 marks]**]*



[max 3 marks]

(e) Qualitatively they would remain the same *[1]*
But the ratios of the horizontal displacements would not be 3. *[1]*

[Note that this has nothing to do with Lorentz contraction]

[max 2 marks]

G2. (a) $\Delta m = m_C - m_N = 1.68 \times 10^{-4}$ u *[1]*

[The β is already included in the atomic masses given. If it is subtracted, Δm is –ve, which should set off some alarm bells!?]

$\Delta E = \Delta m\, c^2 = 1.68 \times 10^{-4} \times (940 / 1.008665)$ *[1]*
(ECF from Δm)

$= 0.157$ MeV *[1]*
[max 3 marks]

[Crazy conversion factor forced on candidates by data given in Data Booklet (one of three possible). Hopefully the candidates have something more sensible stored in their calculators!]

(b) (i) $K_\beta = 0.157/ 2$ MeV $\Rightarrow$ Required ratio $= 0.0785/ 0.511$ *[1]*
(ECF from (a))

$= 0.154$ *[1]*
[max 2 marks]

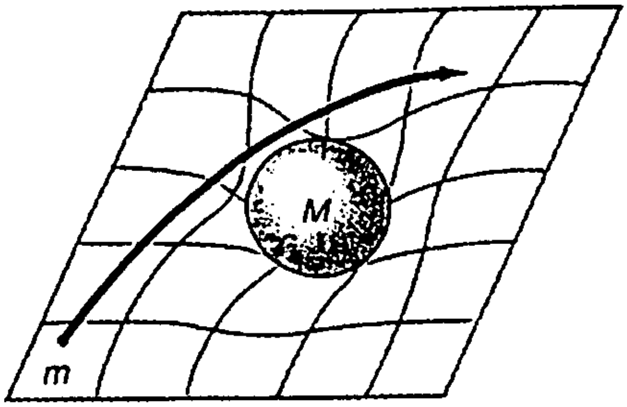
(ii) *[(b) (i) implies that the calculation must be relativistic.*
Correct use of $\frac{1}{2}\,mv^2$ *pays +* ***[1 mark]*** *(generous at that!)*
$\Rightarrow v = 1.66 \times 10^8$ m/s $\rightarrow$ *more alarm bells!?]*

$K = (\gamma - 1)\, mc^2 \Rightarrow K_\beta/mc^2 = 0.153 = \gamma - 1$ *[1]*

(ECF from (b) (i))

algebra: $\gamma = 1.153 \Rightarrow 1 - v^2/c^2 = 1 / 1.153^2$ *[1]*
$\Rightarrow v/c = \sqrt{[\,1 - 1/1.153^2]} = 0.498 \Rightarrow v = 0.50c$ *[1]*
[max 3 marks]

G3. (a) Space-time is curved near the sun (*i.e.* near massive objects) and *[1]*
light, in taking the shortest space-time route, follows a curved path *[1]*
thus changing direction. *[1]*
OR
A good diagram – the 'usual' 'contour diagram' (see below) *[2]*
plus some explanation as above. *[1]*



[max 3 marks]

(b) He compared photographs showing the positions of some 'fixed stars' viewed normally (at night) and when their light passed close to the sun. (taken six months apart - see Figure 1). *[1]*

In order to photograph them for the latter case, the sun had to be obscured by a total eclipse. *[1]*

Due to bending of their light paths, their apparent positions had moved 'out'; *i.e.* there was an apparent greater angular separation between them - see Figure 2. *[1]*

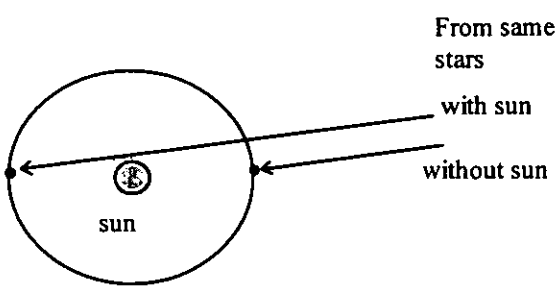


Fig. 1 (not to scale!)

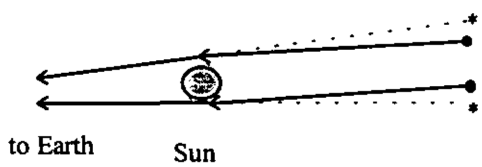


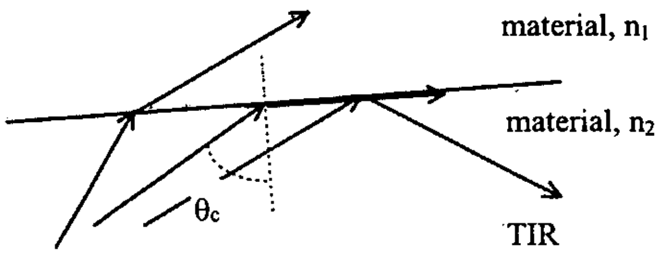
Fig. 2

Give credit for any meaningful diagram:
Figure 1 – up to ***[1 mark]***
Figure 2 – up to ***[2 marks]***

[max 3 marks]

OPTION H — OPTICS

H1. (a) A diagram such as this plus a few (sensible) words of explanation (see below) pays full marks.



Rays must be incident from the 'more dense' side. (refracted ray must bend away from the normal) *[1]*

Critical angle occurs when the angle of refraction is 90°. *[1]*

Diagram: At least two rays should be shown, one of which must be at the critical angle. *[1]*

[Reference to sin $\theta_c = n_1/n_2$ is not required here (but could be great).]

[max 3 marks]

(b) In TIR almost 100% of the energy is reflected. *[1]*
Even in the best mirrors > 50 % may not be reflected.

[max 1 mark]

(c) Full marks for this question requires a discussion about maximising the critical angles involved.

A cladding is used to ensure that there is a well defined boundary from which TIR can take place. (The fibre must ultimately be placed in a protective jacket of some sort). *[1]*

ANY reference to sin $\theta_c = n_{clad}/n_{core}$, even implicitly
e.g. n_{clad} being only slightly less than n_{core} means that the critical angle is large *[1]*

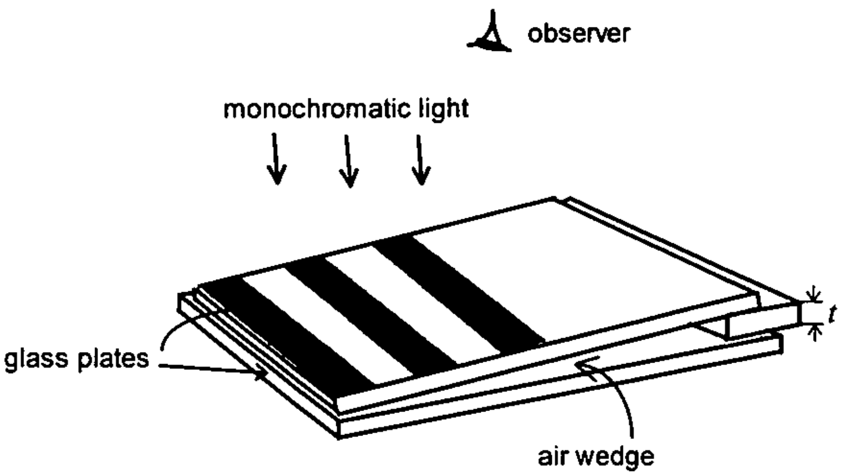
[typically > 75°]
The idea is to maximise the critical angle, (yet preserve the boundary!), in order that only rays that are ~ parallel to the fibre axis pass down the fibre (thus 'laser optics' are used to produce such sources of light). This ensures that pulse spreading is minimised and hence volume of data transmitted maximised.

Any discussion along similar lines. *[1]*

[max 3 marks]

H2. (a) (i) The aim here is to test whether the alignment is correct - parallel to the edge where the two glass plates touch. *(The fringes should start with a dark fringe at this edge — not essential for* ***[1 mark]****.)*

[max 1 mark]

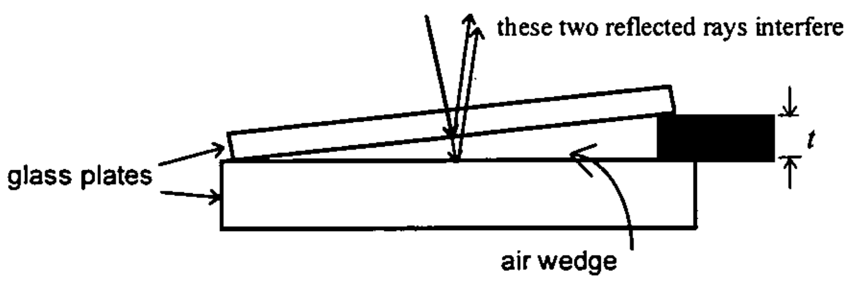


(ii) 'Caused by interference / superposition' only gets ***[1 mark]*** ***[1]***
Correct rays on diagram ***[1]***

Plus any ***one*** *of the following (or other detail)* ***[1]***

- rays partially reflected from the top and bottom of the air film boundaries.
- as the air wedge increases in thickness, the path difference/ phase difference increases.
- from one fringe (dark or light) to the next, the air wedge thickness has increased by $\lambda/2$.
- black edge occurs due to π phase shift on reflection (off lower interface) and the air film is very thin ($<< \lambda$), so path difference $<< \lambda$.

[max 3 marks]



(b) Count the number of fringes along the length, *N* *(these should be dark fringes - not essential)* ***[1]***
thickness = $N \times \lambda/2$ ***[1]***

[max 2 marks]

(c) There would be bright ('white') fringes tinged with colour. *[1]*

This is because it is not possible to eliminate all wavelengths at the same position. *[1]*

Whenever one end of the spectrum suffers destructive interference another is close to constructive interference, so the fringes are tinged reddish and bluish. *[1]*

OR *any **one**, relevant, other detail*
e.g. The 'touching edge' is still dark since all wavelengths suffer destructive interference when the air film is very thin (<< λ).
*[If they say that the bright fringes are multi-coloured because of the different wavelengths present in white light award **[2 marks]**. Fringes are coloured gets only **[1 mark]**]*

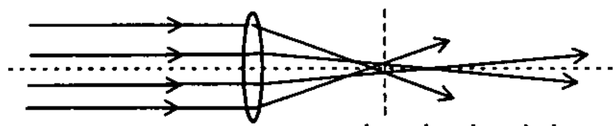
[max 3 marks]

(d) The 'wave' model.

[max 1 mark]

H3. (a) Spherical aberration is reduced. Discussion of 'circles of least confusion' is fine. *[1]*

Diagram correctly showing different focal points and / or circle of least confusion *[1] + [1]*



[max 3 marks]

(b) Focal length of the lens is 35.0 mm (film must be in the focal plane). *[1]*
[max 1 mark]

(c) $1/f = 1/u + 1/v$ *[1]*
$\Rightarrow 1/v = 1/0.035 - 1/1.2 = 28.57 - 0.8333 = 27.74$ (ECF from (b))
$\Rightarrow v = 0.0361$ m *[1]*
$\Rightarrow$ distance to move = 1.1 mm *[1]*
[max 3 marks]

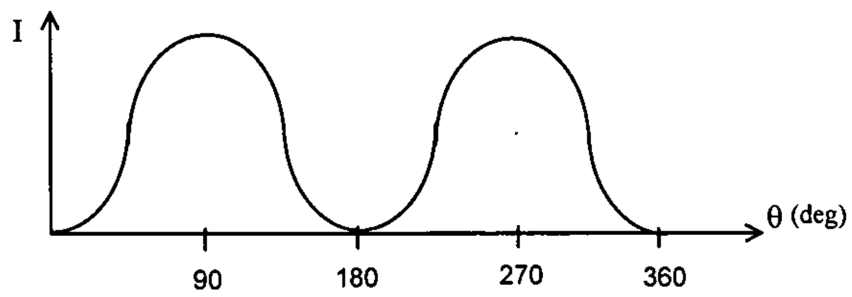
H4. (a) The light passing through Sheet A is plane-polarised. *[1]*
The transmission axis (or 'easy axis' or other acceptable synonym) *[1]*
of sheet B must be oriented at right angles to that of sheet A. *[1]*

*[Statements such as 'sheet B is perpendicular to sheet A' are nonsense – **[1 mark]** only]*

[Discussion in terms of molecular alignment is acceptable (of course).]
[Note that the 'transmission axis' is perpendicular to the molecular alignment].

[max 3 marks]

(b) curve starts at 'zero'. *[1]*
maxima and minima alternate every 90° *[1]*
nice (symmetric!) '$\cos^2$' shape *[1]*



[max 3 marks]