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PHYSICS

Standard Level

Paper 3

24 pages

OPTION A — MECHANICS EXTENSION

A1. (a)

	gravitational potential energy	**kinetic energy**	**elastic potential energy**
From platform to **A**	decreasing	**increasing**	constant (or zero)
From **A** to **B**	decreasing	increasing	increasing
From **B** to **C**	decreasing	decreasing	increasing

Gravitational Potential Energy – complete column correct *[1]*
Kinetic Energy – A $\rightarrow$ B, increasing (hard) *[1]*
– B $\rightarrow$ C, decreasing *[1]*
Elastic Potential Energy – $\rightarrow$ A, constant *[1]*
– A $\rightarrow$ B **and** B $\rightarrow$ C, increasing *[1]*
[max 5 marks]

(b) $\Delta K + \Delta U = 0$ or $\frac{1}{2}mv^2 = mgh$ *[1]*
[no marks for KE = $\frac{1}{2}mv^2$ on its own]
$\Rightarrow v = \sqrt{(2gh)} = \sqrt{(2 \times 9.8 \times 26)} = 23$ m/s
OR $= \sqrt{(2 \times 9.8 \times 27)} = 23$ m/s *[2]*
*[use of h = 25 m $\Rightarrow$ v = 22 m/s only gets **[2 marks]** max]*
*[use of h = 45 m but otherwise correct gets **[2 marks]**]*
[max 3 marks]

(c) $F_{resultant} = F_{cord} - F_{grav}$ *[1]*
*[F = kx and x = 20 m gets **[1 mark]***
x = 45 m gets no marks]
$= k\Delta x - mg$ *[1]*
$= 75 \times 20 - 54 \times 9.8 = 1500 - 529 = 971$ (= 970) N *[1]*
Resultant force is UP - implied in the above calculation.
*If the calculation is in error but the direction is clearly recognised pay (at least) + **[1 mark]***
[F = mg alone gets no marks]
*[use of x = 45 m with appropriate calculation (F_{res} = 2850 N) gets **[2 marks]**]*
[max 3 marks]

(d) In her final (equilibrium) position, $F_{cord} = k\,\Delta x = mg$ *[1]*
$\Rightarrow \Delta x = mg / k = 54 \times 9.8 / 75 = 7.06$ (= 7.1) m *[1]*
[max 2 marks]

A2. (a) $g_m = GM/R^2$ *[1]*

$= G \times 7.35 \times 10^{22} / (1.74 \times 10^6)^2$

$= 1.62\ ms^{-2}$ *[1]*

[max 2 marks]

(b) Time to fall 5.0 km: $s = ½\, g_m\, t^2$ *[1]*

('ECF' from (a))

$\Rightarrow t = \sqrt{(2s / g_m)} = \sqrt{(2 \times 5000 / 1.62)} = 78.6$ s. *[1]*

Horizontal speed required = 10000 / 78.6

$= 127\ (= 130)\ ms^{-1}$ *[1]*

[max 3 marks]

(c) $(m)v^2/R = (m)\, g_m$ *[1]*

('ECF' from (a))

$\Rightarrow v = \sqrt{(R\, g_m)} = 1680$ m/s *[1]*

[max 2 marks]

OPTION B — ATOMIC AND NUCLEAR PHYSICS EXTENSION

B1. (a) The presence of neutrons increases the average separation between protons hence reducing the electrostatic repulsion *[1]*
Neutrons are attracted to protons and other neutrons by the strong nuclear force *[1]*
or neutrons increase the binding energy *[1]*

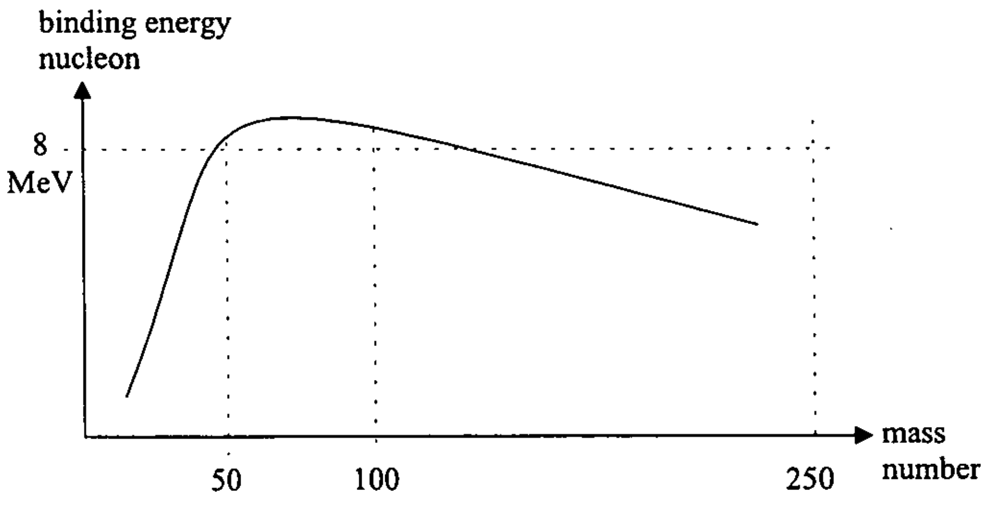
[max 2 marks]

(b) (i) Nuclear binding energy is normally defined as a positive quantity:
– the energy required to separate/ disassociate a nuclear structure into its component protons and neutrons.
– the energy released when individual neutrons and protons are combined to form a particular nucleus.
– the energy corresponding to the mass deficit between the sum of the masses of the individual neutrons and protons and the mass of the resulting nucleus.

or similar?!

[max 1 mark]

(ii) Indication of scale (one point on each axis is sufficient) *[1] + [1]*
General shape *[1]*
Maximum > 8 MeV and in the region of A = 50 to 75. *[1]*
[Accept a negative curve for full marks]



[max 4 marks]

(b) (iii) In a natural (nuclear) process energy must be released. *[1]*
When two light nuclei combine to form one with $A \approx 50$,
the single nuclear mass is less than the sum of the two constituents and the mass difference is released as energy *[1]*
and
when a heavy nucleus splits to form two with $A \approx 115$ each (average, but unlikely split), the combined masses of the products is less than that of the original nucleus and the mass difference is released as energy. *[1]*

[1 mark] **only** for brief answers/ comments such as: Both lead to a release of energy **or** are energetically possible **or** produce products that are more stable, *etc.*

[max 3 marks]

B2. (a) The main aim of this question was to broadly test knowledge of the acceleration and passage of charged particles in magnetic fields. Only some, NOT detailed, mathematics is required. Answer must contain an acceleration phase ***[1 mark]***, the separation phase ***[2 marks]*** and a diagram ***[3 marks]***, with the possibility of some variation in marks per section.
[An answer which shows a reasonable grasp should gain full marks]

acceleration phase: implicit or explicit realisation *[1]*
[some details (note that the masses of the ions are the same):
acceleration is modest, several kV; kinetic energies of He^{+} and He^{++} are different;
$KE^{+} = eV$; $KE^{++} = 2eV \Rightarrow v^{++} = \sqrt{2}\, v^{+}$].

separation phase: reasonable (consistent) diagram - see below. ***[max 3]***
This should: show an acceleration region *[1]*
accurately show the separation process and final He^{++} path *[1]*
shows correct orientation of **B** and/or **E** fields *[1]*

The most common answer (?) will probably send the ions into
Magnetic Separation:
Principle: ions are passed though a magnetic field perpendicular to their velocity & their separation is based on different accelerations produced by the magnetic force: *[1]*

mag. force $= qvB = mv^2/r$ $[\Rightarrow r = mv/qB]$ *[1]*
[They probably will not realise that the velocities are not equal; do NOT deduct marks]

[Note: An extra mark can be gained by realising that $r(He^{++}) < r(He^{+})$,
since $q^{++} = 2e$ (& $v^{++} = \sqrt{2}v^{+}$)*]*.

[Note: Some may precede this with a velocity selector (assuming both ions go through with the same speed) - just ignore - magnetic separation gets 'full marks' whether or not a velocity selector is included; some may realise that a velocity selector is in itself a separation process.]

<u>velocity selector/ filter</u> where ions of the same speed pass through. *[1]*

Principle: crossed magnetic and electrostatic fields (shown on diagram), arranged to give equal (and opposite) forces on the He: $qv^{++} B = qE$ [$\Rightarrow v^{++} = E/B$]. *[1]*

[If He^{++} *goes straight through,* He^{+} *will be diverted in the direction of* **E** *(this is 'hard'):*
If $F_E^{++} = 2eE = F_M^{++} = 2e\, v^{++} B$, *then* $F_E^{+} = eE = e\, v^{++} B = e\sqrt{2}\, v^{+} B = \sqrt{2}\, F_M^{+}$*]*.

<u>Electrostatic</u>: It is not possible to separate ions with different charges but accelerated through the same potential difference. This is hard stuff and it is unlikely that any candidate will take this path. However, if they assume (implicitly) that both ions have the same speed then up to full marks should be awarded for consistency, *etc.*

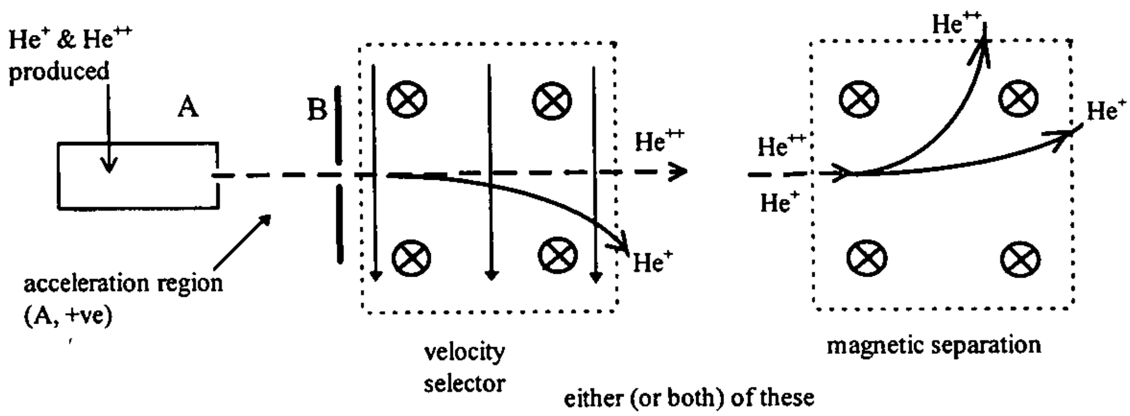
Principle: ions injected between parallel plates (as in a CRO) and suffer a 'perpendicular deflection': force on $He^{++} = 2 \times$ force on He^{+} *[1]*
$\Rightarrow$ acceleration $He^{++} = 2 \times$ acceleration He^{+} *[1]*
$\Rightarrow$ tighter curve (parabola) for He^{++} (ASSUMING equal initial speeds).

OR

ions forced to moved in a circle between annular 'parallel plates' with the necessary centripetal force provided electrostatically:
force on $He^{++} = 2 \times$ force on He^{+}. *[1]*
and $mv^2/r = qE$ *[1]*
$\Rightarrow r(He^{++}) < r(He^{+})$ (ASSUMING equal speeds).

[An equal accelerating voltage, V_{accel}, $\Rightarrow r = mv^2 / qE = 2qV_{accel} / qE = 2\, V_{accel} / E$ *, for BOTH!]*.

[max 6 marks]



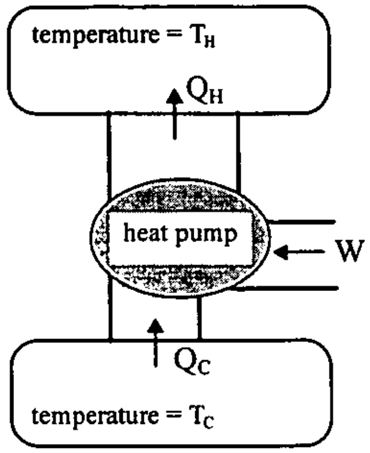
(b) Came from radioactive α-decay *[1]*
Plus [1 mark] for any one of: *[1]*
He^{++} is an alpha particle / decay of 'heavy' elements *e.g.* radium /
α-particles have a well defined energy

[max 2 marks]

(c) The Bohr model only works for single electron atoms or ions. *[1]*
Hence it works for $He^{+} \rightarrow He^{++}$, but not for He (2 electrons) to He^{+}. *[1]*
[max 2 marks]

OPTION C — ENERGY EXTENSION

C1. (a)



Q_C = heat extracted from the cooler reservoir
Q_H = heat delivered to the hotter reservoir
T_C = temperature of the cooler reservoir
T_H = temperature of the hotter reservoir
W = work done on the heat pump

Correct T_H and T_C *[1]*
Correct W *[1]*

[Incorrect T_H & T_C *will give illogical/ inconsistent/ meaningless heat energy transfer].*
[max 2 marks]

(b) $Q_H = Q_C + W$

[max 1 mark]

(c) Work W ($\neq 0$) must be done (on the heat pump) to facilitate the energy transfer.

[max 2 marks]

(d) (i) COP = (273 + 45)/ (45 – (–5)) = 6.36 *[2]*

(Watch for bogus calculations!?)

incorrect conversion 45°C → K *[–1]*
incorrect temperature difference *[–1]*
[max 2 marks]

(ii) The heat pump must provide 1.5 kJ per second, *[1]*
hence
COP = 1500 Js^{-1}/ W *[1]*
⇒ W = 1500/ 6.4 = 230 W (Js^{-1}) *[1]*
[If a COP of 3.36 is used then W = 236W]
[max 3 marks]

(iii) *Either one of (or both):*
W would be greater or
the heat energy transferred would be less ***[max 1 mark]***

C2. The solar panels are required to provide
$12\ \text{kW h} = 12 \times 10^3 \times 3600$ J (= 43.2 MJ per day). *[1]*
Assumption: ***[2 marks]*** **max.**
The panels can provide 70 Wm^{-2} in direct sunlight, so we need to assume something about the average number of hours of effective 'direct sunlight'. *[1]*

[**Note**: some candidates may get bogged down at this point with angular considerations (of the sun's rays), *etc.* Be sympathetic. The ***[1 mark]*** above is for this sort of dilemma. But ultimately they must come up with a number.]

This could vary widely, say between 2 and 6 h. *[1]*

Then, energy available per day per square metre of panel area
$= 70 \times (2 \rightarrow 6) \times 3600$ (= $(5 \rightarrow 15) \times 10^5$ J). *[1]*

$\Rightarrow$ Area required $= 12 \times 10^3 \times 3600 / (70 \times (2 \rightarrow 6) \times 3600) = 86 \rightarrow 28\ \text{m}^2$ *[1]*

[max 5 marks]

C3. ***[1 mark]*** *for each correctly filled 'box'.*

Convert FROM ⇓ TO ⇒	**electrical**	**mechanical**	**thermal**
electrical	transformer	electric motor	**resistance heating** **'electrical heater', stove, kettle, *etc.***
mechanical	**generator** **MHD generator (magnetohydro - dynamic)**	**levers, pulleys** **bicycle** **windmill**	heating by friction
thermal	thermoelectricity	**geo-thermal steam engine** **any heat engine** **turbine**	———

[max 4 marks]

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 $\Rightarrow$ 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;
$\Rightarrow$ 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]*
reference to $Q \sim R^4 \Delta P$ *[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]*

[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 (what?)

[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]*
– broadband / uniform loss with frequency *[1]*

[max 4 marks]

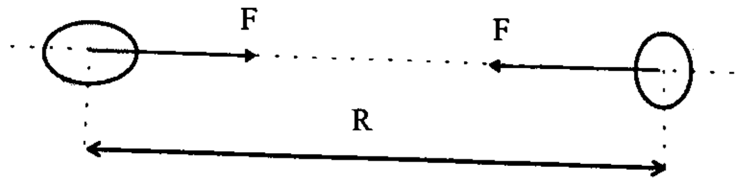
OPTION E — HISTORICAL PHYSICS

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

(b) ALL matter attracts ALL matter. *[1]*
The gravitational force extends beyond the 'Earth's sphere'/ thoughout the <u>universe</u>. *[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) Acceleration due to gravity at the Moon's orbit $= 9.81 \times (6.37 \times 10^6 / 3.84 \times 10^8)^2$ *[2]*

$= 9.81 \times (1/60)^2 = 0.0027\ \text{ms}^{-2}$ *[1]*
[max 3 marks]

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 (and presumably will be the most common answer) was the 'paddle wheels in water' experiment. He made all sorts, including 'single and double sided' arrangements.
Reasonable diagram conveying main idea *[1]*
2 - 3 labels for important features *[1]*
(thermal insulation/ calorimeter, masses/ weights, water (?!), thermometer)
More labels/ details *[1]*
*[Award only **[1 mark]** for hammer with lead sheet]*

[max 3 marks]

E3. (a) Light was modelled / treated as a stream of particles of energy, E = hf. *[1]*

The interaction between light and electrons was envisaged as a 'billiard ball' type collision. (*i.e.* something along these lines *e.g.* each photon knocks out one electron) *[1]*

Controversial because the wave model/ theory was strongly supported by other experiments that the photon theory could not explain (wave superposition - interference, diffraction). *[1]*

[max 3 marks]

(b) *There are the four 'classic' points from which to choose* ***one****:*
Description of aspect *[1]*
Photon explanation *[2]*

aspect	**photon explanation**
existence of a cut-off	E = hf plus minimum energy for electron emission (= work function, ϕ) *[plus 'one-to-one' interaction]*
K_{max} independent of light intensity	intensity determined by number of photons NOT their energy, which remains the same (E = hf); *[plus 'one-to-one' interaction]*
K_{max} increases with frequency (as opposed to intensity)	$K_{max} = hf - \phi$, and 'as above'
no time delay for electron emission	'one-to-one' interaction

[max 3 marks]

OPTION F — ASTROPHYSICS

F1.

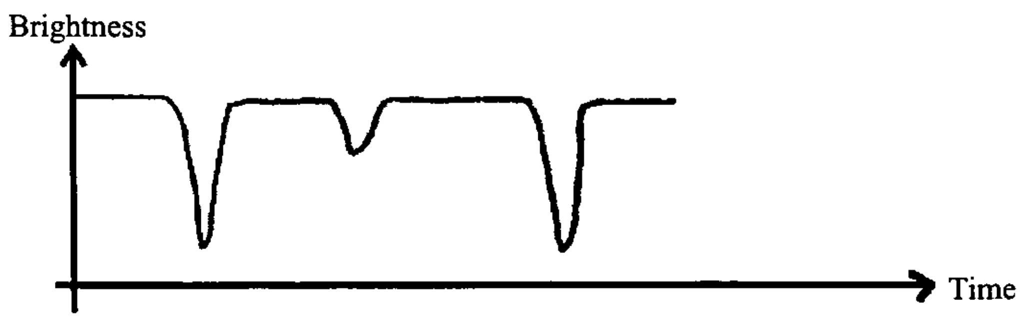
Red giant	[3]	Galaxy	[5]
Jupiter	[2]	Neutron star	[1]
Solar system	[4]		

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

F2. (a) Composition *[1]*
of stars *[1]*
Also, intensities give details of star class
[Accept velocity, elements or compounds]
[max 2 marks]

(b) Why? Due to relative velocity of star and Earth/ the Doppler Effect. *[1]*
What? Can determine the relative velocity of star to Earth [radial component]. *[1]*
[max 2 marks]

(c) *For **[2 marks]**, no great detail was required. **[2 marks]** for either of:*
<u>Variable</u> 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]

(d) Luminosity will increase *[1]*
Colour will change towards red *[1]*
(more energy will be radiated in the red end of the spectrum)
[max 2 marks]

F3. (a) (i) $\lambda_p = 2.90 \times 10^{-3} / T$ *[1]*
$= 2.90 \times 10^{-3} / 3 = 1 \times 1^{-3}$ m. *[1]*

[max 2 marks]

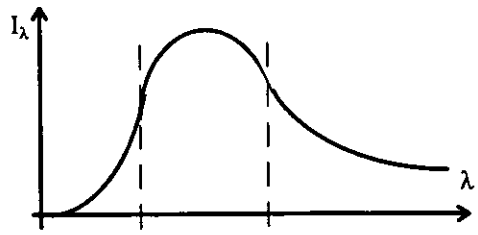
(ii) Spectral region microwave *[1]*
Telescope radio telescope *[1]*

[max 2 marks]

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

[max 2 marks]

(c) Need relative intensity measurements at, at least, two wavelengths in order to obtain a temperature. *[1]*
(Preferably on either side of the peak in the spectral intensity curve, I_λ).



This is hard for Standard Level candidates and some may answer that all wavelengths near the peak need to be measured in order to establish its position. This is acceptable for full marks.

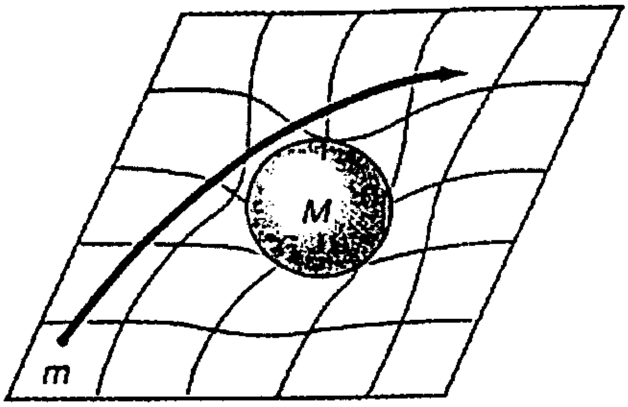
[max 2 marks]

(d) The spectral intensity peak will continue to move to greater wavelengths/ lower temperatures/ lower energies.

[max 1 mark]

OPTION G — SPECIAL AND GENERAL RELATIVITY

G1. (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 6 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 move 'out'; *i.e.* there was an apparent greater angular separation between them - see Figure 2. *[1]*

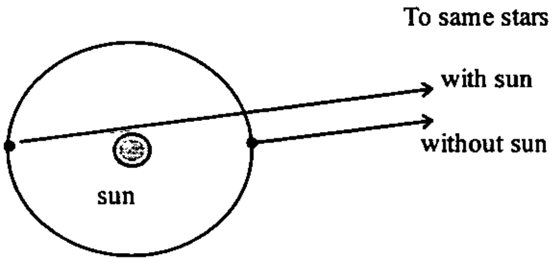


Fig. 1 (not to scale!)

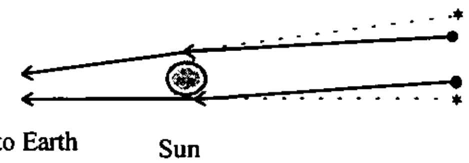
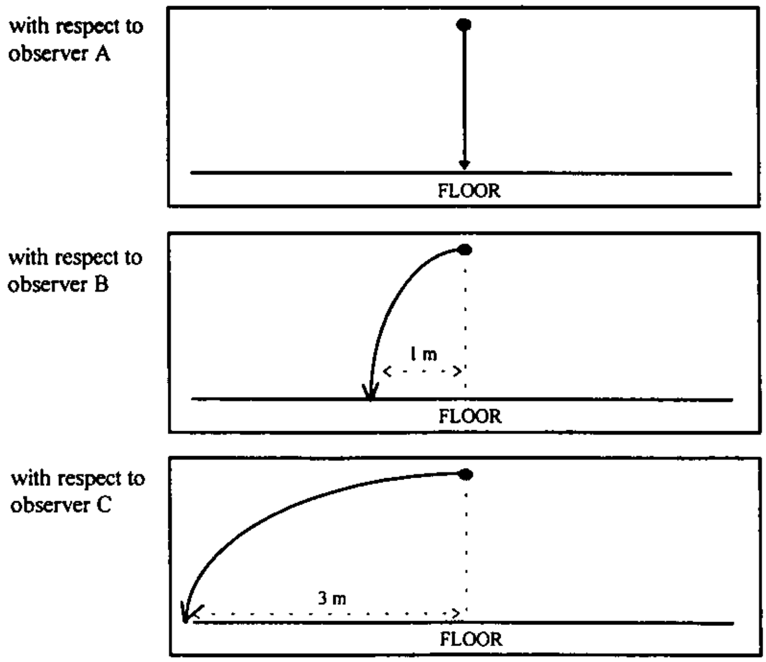


Fig. 2

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

[max 3 marks]

G2. (a) ***[1 mark]*** per correct diagram (general shape/ direction) plus
[1 mark] for correct 1 m AND 3 m horizontal displacement.

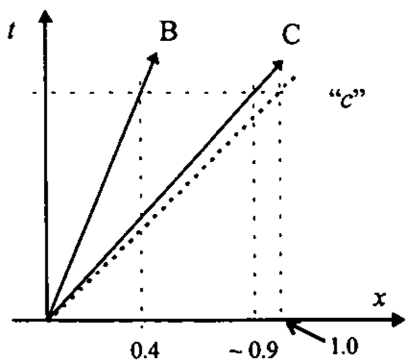


[max 4 marks]

(b) $\Delta t_B = \gamma \Delta t_A$ ***[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]***
('ECF' from γ)
*[If reference systems are confused ($t_B = t_A/8$) award **[1 mark]**]*

[max 3 marks]

(c) 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]***
Both should have 'positive speeds' ***[1] + [1]***
*[If the world lines of B and C are on the other side of 'c' but otherwise correct award **[3 mark]**]*



[max 4 marks]

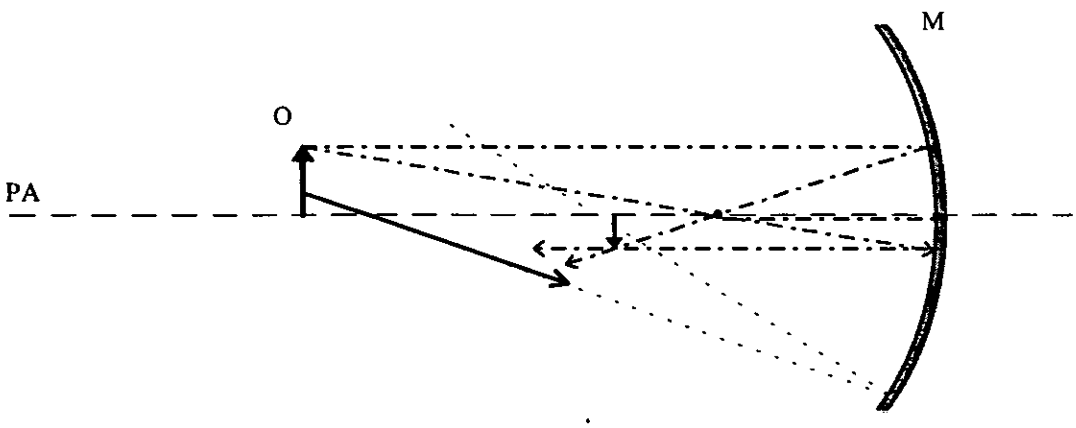
(d) (i) 2.3 kg ***[1]***

(ii) $m_B = \gamma m_A$ ***[1]***
('ECF' from γ in (b))
$= 1.09 \times 2.3 = 2.5$ kg ***[1]***
[max 3 marks]

OPTION H — OPTICS

H1. (a) (i) Position of Principal Focus *[1]*
At least two rays must be shown defining the position of the image. *[1]* + *[1]*
Two alternative rays are
through the centre of curvature (at 2 × the P. Focus distance) - reflects back on itself and at the 'centre' of the mirror which reflects symmetrically (hard to use).
[max 3 marks]

(ii) The extended ray MUST pass through the corresponding point on the image (below half way up). *[1]*
[max 1 mark]



(iii) $1/f = 1/u + 1/v$ *[1]*
$\Rightarrow 1/v = 1/10\text{ cm} - 1/30\text{ cm} = 2/30$ *[1]*
$\Rightarrow v = 15\text{ cm}.$ *[1]*
OR
By measurement off the figure - watch 'ECF'.
There should be some evidence that some form of scaling from the figure has been used.
[Pity the answer is 'exactly' half way between 'O' and the mirror!]. *[1]*
Correct position (± 0.5 cm) *[2]*
[max 3 marks]

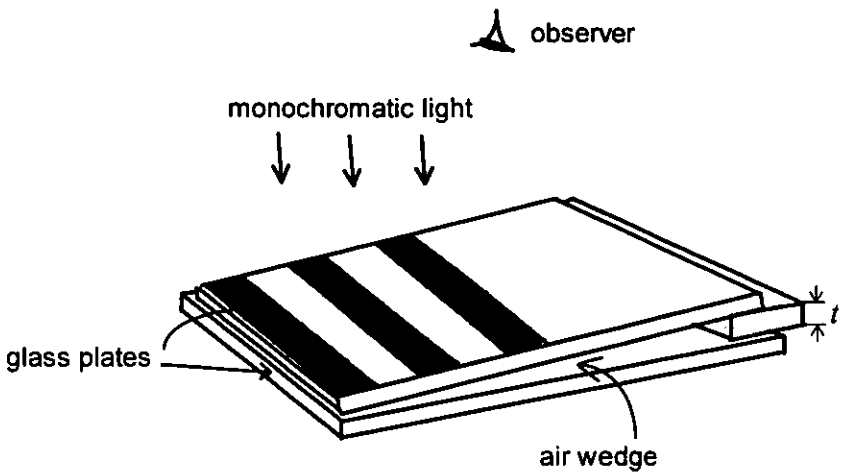
(iv) Only 'real' pays. ***[max 1 mark]***
[Inverted and diminished are already clear from above].

(v) Candle flame would be placed at the P. Focus. ***[max 1 mark]***

(vi) Parabolic. ***[max 1 mark]***

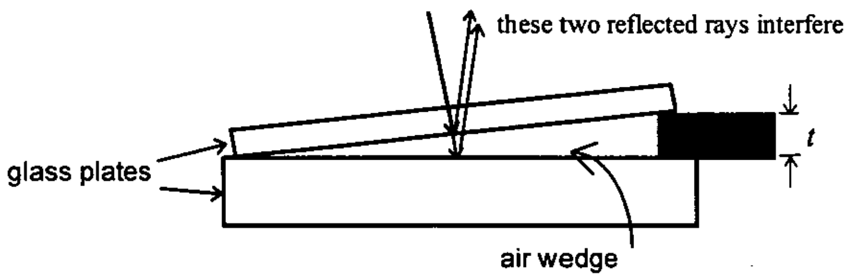
H2. (a) (i) The aim here is to test whether the alignment is correct - parallel to the edge where the two glass plates touch. *[The fringes should start with a dark fringe at this edge but for [1 mark], this is not essential].*

[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 the dark fringes - not essential]* ***[1]***
Thickness = N × $\lambda/2$ ***[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**, other detail, *e.g.*
The 'touching edge' is still dark since all wavelengths suffer destructive interference when the air film is very thin ($<< \lambda$).
*[If they say that the bright fringes are multicoloured 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]***