INTERNATIONAL BACCALAUREATE
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MARKSCHEME

MAY 2000

PHYSICS

Higher Level

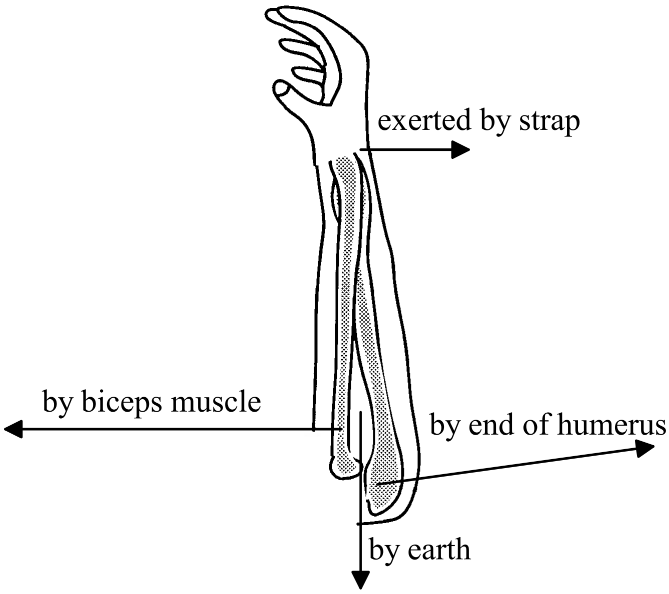
Paper 3

24 pages

D1. Forces in human arm ***[14]***

(a) Sum of forces statement. ***[1]***
Sum of torques statement. ***[2]*** ***[3]***
[3 max]

(b)



*(Award **[4]** for 4 correct forces and names of objects exerting each. Judgements for part marks. (For example, lose **[1]** for omitting humerus force. Judgement if one name is omitted, lose **[1]** if two names omitted))* ***[4]***
[4 max]

(c) $T = F \times d = 100\text{ N} \times 32\text{ cm} = 3200\text{ N cm}$. ***[1]***
Clockwise. ***[1]*** ***[2]***
[2 max]

(d) Greater than. ***[1]***
To get equal torque, muscle force must be greater since lever arm distance is shorter. * *(N.B. No marks for right answer with wrong reason!)* ***[1]***
[1 max]

(e) $Tcw = Tacw$
$100 \times 32 = F \times 4$ ***[1]***
$F = 100 \times \frac{32}{4} = 100 \times 8 = 800\text{ N}$. ***[1]*** ***[2]***
[2 max]

(f) Weight acts vertically and its line of action is through elbow joint ***[1]***,
so it exerts no torque about the elbow joint. ***[1]*** ***[2]***
[2 max]

D2. Walking barefoot on gravel ***[6]***

(a) Mass of man is $2 \times 2 \times 2 = 8$ times the child. ***[1]*** ***[1]***
[1 max]

(b) Force is proportional to mass. Thus force ratio, man to child, $8:1$. ***[1]*** ***[1]***
[1 max]

(c) Area scales as linear dimension squared.
Area ratio, man to child, is $4:1$. ***[1]*** ***[1]***
[1 max]

(d) Force/area scales as $8:4$ or $2:1$. ***[2]***
or
Force/area scales as L cubed over L squared, *i.e.* as L. So ratio is $2:1$ ***[2]*** ***[2]***
[2 max]

(e) Man finds it more painful, since force on a unit area scale of sole is twice that of the child. ***[1]***

(N.B. Don't worry about force being exerted only by the sharp points of stones, since force on each sharp point will be twice as great for the man, following the same reasoning.) ***[1]***
[1 max]

D3. Radioactive tracers ***[10]***

(a) (i) Radioactive half-life:

Time for activity of a radioactive sample to drop to a half. ***[2]***
(Or time for number of radioactive nuclei to drop to a half.)
(Or time for half of radioactive nuclei to have decayed.) ***[2]***
[2 max]

(ii) Biological half-life:

Time for amount of a substance in the body to drop to a half (due to physiological processes). ***[2]*** ***[2]***
[2 max]

(b) In 6 days, three biological half lives elapse, so $\frac{1}{2}\times\frac{1}{2}\times\frac{1}{2}=\frac{1}{8}$ th remains in body. ***[1]***
In 6 days, activity of any portion drops to $\frac{1}{2}\times\frac{1}{2}=\frac{1}{4}$ ***[1]***
So activity remaining in body is $\frac{1}{8}\times\frac{1}{4}$ or $\frac{1}{32}$ of original activity. ***[2]*** ***[4]***
[4 max]

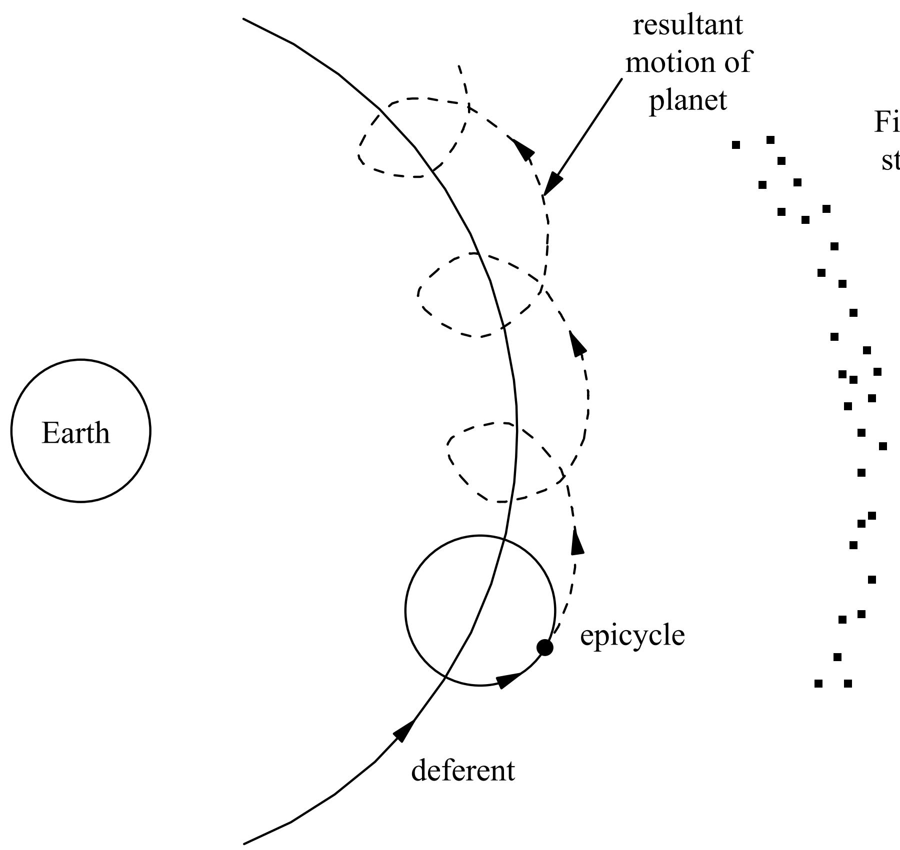
(c) The tracer should have a reasonably high activity throughout the physiological investigation, to 'trace' as desired. If it had a shorter half-life, activity would diminish a lot during the investigation, reducing sensitivity. ***[2]*** ***[2]***
[2 max]

E1. Models of the universe ***[12]***

(a) (i) Stars were embedded in a celestial sphere which rotated about the earth. ***[2]***
[2 max]

(ii) Moon was carried on another, smaller sphere, also rotating about the earth, but with a somewhat slower rotation. ***[2]***
[2 max]

(iii)

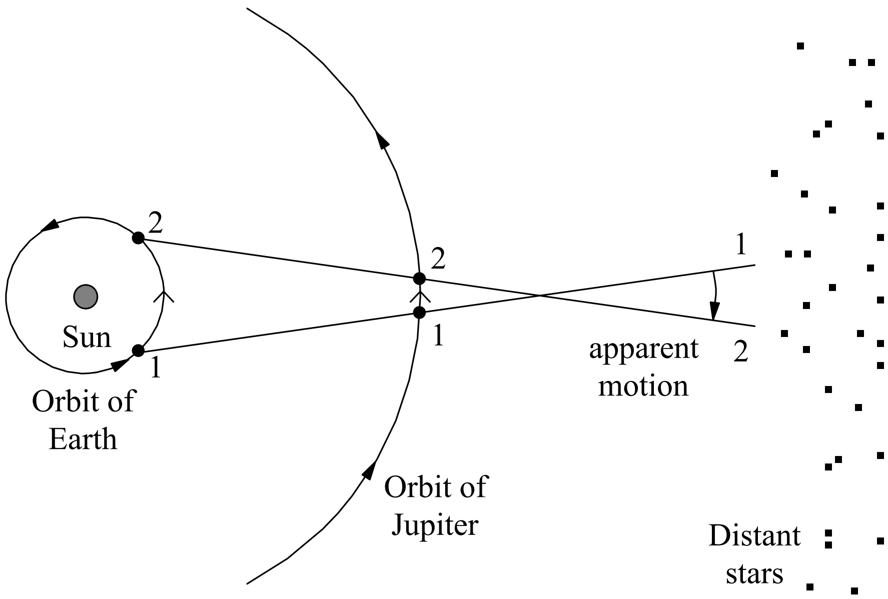


In addition to their own celestial sphere motion (on the main cycles or equants), the planets performed epicycles. During the time that motion on an epicycle was in the opposite direction to main cycle motion, the net motion was ‘backwards’. ***[3]***
[3 max]

continued...

Question E1 continued

(b) *Copernican model.*



(i) Award ***[1]*** for showing Earth a quarter circle further, and Jupiter about half that distance further. ***[1]***

(ii) Both Earth and Jupiter rotate about the sun, but Jupiter is slower. As observed from an earth which shifts position, Jupiter appears to reverse its motion at times, against the fixed stars, as shown in the sketch. ***[2]***

[3 max]

(c) Kepler gave up trying to describe the motion in terms of combinations of circles (cycles, epicycles and equants), ***[1]*** and found that an **elliptical** orbit matched the observations precisely. ***[1]*** ***[2]***

[2 max]

E2. Cannon boring and caloric ***[8]***

(a) Caloric fluid was set free from a material when it was cut up into small pieces. ***[2]***

(Note that the smaller pieces would then have a smaller heat capacity than the original large piece.) ***[2]***

[2 max]

(b) Prediction: Since less material was cut and fewer shavings produced, so less caloric fluid would be freed, so less heat would be generated. ***[1]***
Yet this was not observed. (Just as much heat was produced.) ***[1]*** ***[2]***

[2 max]

(c) Rumford's own words were: "Anything which ... a system of bodies can continue to furnish *without limitation* cannot possibly be a material substance ..."

(Any reasonable statement of these ideas. ***[2]****)* ***[2]***

[2 max]

(d) Rumford's words: "... difficult to form any idea of anything capable of being excited ... in the manner which heat was excited ... in these experiments, except it be MOTION".
In our terms, work done in boring was the source of the heat generated.
Accept answers using the reasoning: Apparent brightness → luminosity → intensity → Stefan-Boltz.

(Any reasonable statement of these ideas. ***[2]****)* ***[2]***

[2 max]

E3. Virtual particles and forces *[10]*

(a) Note that syllabus does not mention uncertainty principle **explicitly** so one just has to state/accept it implicitly.

Particle can be created, violating conservation of energy by ΔE, provided time of existence is short enough that $\Delta E \Delta t < h$. *[2]*

[2 max]

(b) Virtual particle emitted by one charge, which recoils. *[1]*
Particle absorbed by second charge, which recoils. *[1]*
Continuing process. Net effect is both charges experience force away from each other. *[1]* *[3]*

[3 max]

(c)

Force	Exchange particle	Range of force (infinite or short range)	
1. **Gravitation**	graviton	**Infinite**	*[1]*
2. Electromagnetic	photon	**Infinite**	*[1]*
3. **Weak nuclear**	$W^{\pm}$, Z^{0}	**Short**	*[1]*
4. **Strong nuclear**	**pi meson**	**Short**	*[2]*

[5 max]

F1. Stellar distances ***[8]***

(a) The star is closer than the others, close enough to earth that parallax effect is observable. ***[1]***
[1 max]

(b) Derivation with sketch.
[2] for right idea about parallax method, including diagram.
[2] for details and approximation. ***[4]***
[4 max]

(c) Hubbles's law required measurable redshift, *i.e.* recession velocity at least some small fraction of the speed of light. ***[1]***
Nearby star may not be receding, and if it was it would be too slow, since recession speed depends on distance. ***[1]***
Hubble's law can be used for distant galaxies. ***[1]***

Also accept, for part credit, that 'local' velocities (including those of the earth and sun) are dominant. ***[3]***
[3 max]

F2. Hertzsprung-Russell diagram ***[22]***

(a) Absolute magnitude. ***[1]***
Must be an inherent property of a star, not an observed property which also depends on distance away. ***[1]***
(But no marks for right answer with wrong reasoning.) ***[2]***
[2 max]

(b) ***[2]*** for two of the following three reasons:
To cover a wide range of orders of magnitude ***[1]***
and because relative (ratio) differences between magnitude are important, which is reflected in a log scale. ***[1]*** The smaller values would be lost on an absolute scale.
Of historical origin – judged comparative brightness by eye in assigning magnitudes, 1.2,3 *etc.*, and eye response is more logarithmic than linear). ***[1]*** ***[2]***
[2 max]

(c) Surface temperature. Temperature values are determined from radiation received, which comes from the surface of the star. ***[2]***
[2 max]

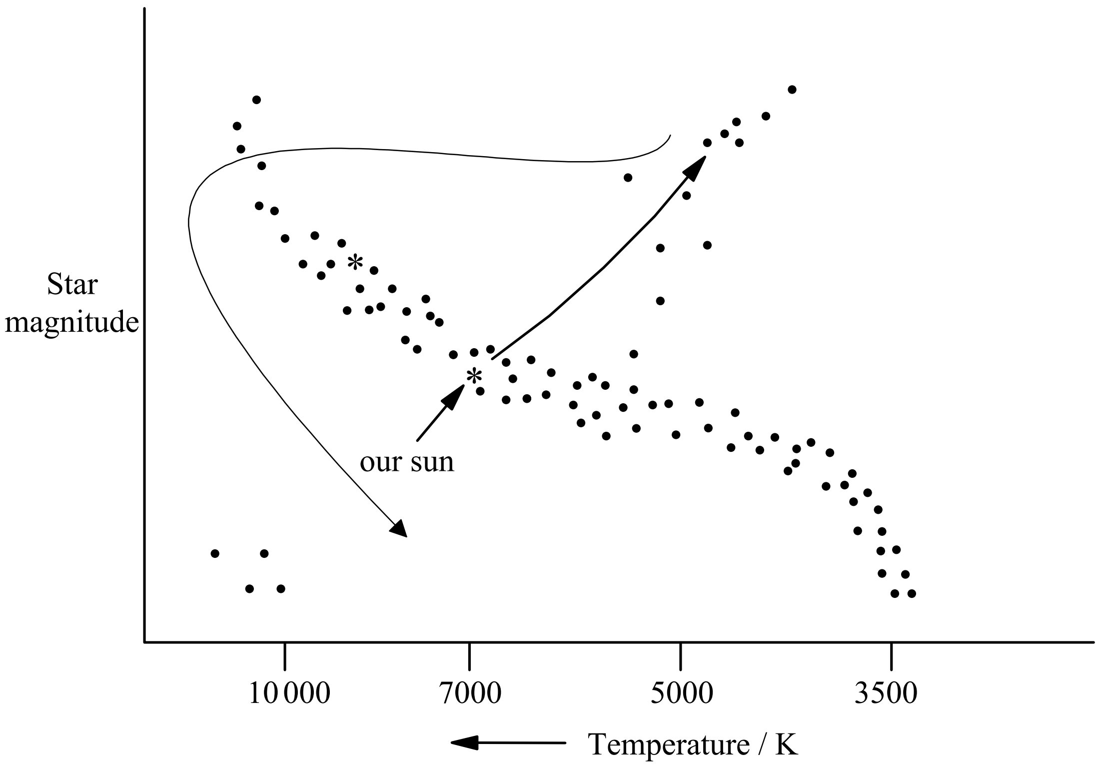
(d) Analyse spectrum of radiation. ***[1]***
From peak (maximum intensity) of continuous distribution of wavelengths, can determine temperature using Wien's law. ***[1]*** ***[2]***
[2 max]

continued...

Question F2 continued

(e) (i) Luminosity greater and colour bluer. ***[1]***
Greater luminosity due to greater size and greater energy production. ***[1]***
Bluer due to higher temperature from greater energy production. ***[1]*** ***[3]***
[3 max]

(ii) ***[1]***
[1 max]



(f) (i) Explanation of why it leaves the main sequence. ***[2]***
Description of processes in becoming a red giant. ***[2]*** ***[4]***
[4 max]

(ii) Explanation. ***[2]*** ***[2]***
[2 max]

(iii) Roughly correct path on diagram (*i.e.* going left and then down as shown). ***[1]*** ***[1]***
[1 max]

(iv) White dwarf or black dwarf both acceptable. ***[1]***
Description of white dwarf or black dwarf. ***[2]*** ***[3]***
[3 max]

G1. Relativity and simultaneity ***[12]***

(a) ***[1]*** for each postulate. ***[2]*** ***[2]***
[2 max]

(b) Could give sketch of situation (not required however):

Then show train moved a bit, toward one platform scorch mark and away from the other. Given that S sees flashes, travelling toward S with speed of light, as simultaneous. Observer T, moving relative to S, will be in a different position from S when flashes arrive, so for T they will *not* arrive simultaneously. The one coming from the front of the train will arrive first.

Since the speed of light for T will also be c, (irrespective of fact that T is moving relative to S), T will explain the different times of arrival, having travelled equal distances, as due to the flashes not having occurred simultaneously.

[1] for explanation of flashes not arriving simultaneously for T.
[1] for speed of light still c for T.
[1] for infer flashes did not occur simultaneously.
[1] for overall understanding, coherence and quality. ***[4]***
[4 max]

(c) T will say the front strike occurred first. ***[1]***
[1 max]

(d) For T: 100 m ***[1]***
For S: $\frac{100}{\gamma}$ ***[1]***
$= \frac{100}{1.15} = 85$ m ***[1]*** ***[3]***
[3 max]

(e) For S: 85 m (Simultaneous marking of train and platform at ends, and train is length contracted according to S). ***[1]***
For T: $\frac{85\text{ m}}{\gamma} = \frac{85}{1.15} - = 74$ m ***[1]*** ***[2]***
[2 max]

G2. Space capsule ***[12]***

(a) Experiment does not help distinguish. ***[1]***
Lee would explain acceleration as due to gravitational force on the hammer. ***[1]***
Anna would say that if the spaceship is accelerating, the floor of the capsule accelerates toward the hammer ***[1]***,
which just remains in the state of motion it had when released. ***[1]*** Hammer has not accelerated.
(The above allocation is a guide: be flexible in awarding marks for explanations, looking for overall understanding.) ***[4]***
[4 max]

(b) *Second experiment:*

(i) Photons would lose energy as they go up against the gravitational field, thus photon frequency would decrease slightly, *i.e.* red shift. ***[2]***

(ii) Each wave front of light would be detected in a frame which was moving slightly faster than the previous one, so that frequency of wave fronts detected would be less, *i.e* shifted toward the red. ***[2]***
[2 max]

(c) No. Equivalence principle ***[1]***.
(Actually no or yes! A planetary gravitational field is not uniform, though very nearly so across the capsule. So, if they released two objects simultaneously, one above the other, the distance between them would increase as they fell (slightly). No student is likely to think of this, but accept either answer no or yes with supporting statement.) ***[1]***
[1 max]

(d) Anna is likely to be right. ***[1]***
If a spaceship had taken off from the planet, there would have been a stage where sensation **increased** during blastoff, only later diminishing. ***[2]*** ***[3]***
[3 max]

G3. Decay in flight

(a) Galilean:
$0.5\text{ c} + 0.7\text{ c} = 1.2\text{ c}$ ***[1]***
[1 max]

(b) Relativistic:
Relativistic velocity addition:

$$u = \frac{(u' + v)}{\left(1 + \frac{u'v}{c^2}\right)}$$ ***[1]***

$$= \frac{(0.7\text{ c} + 0.5\text{ c})}{\left(1 + \frac{0.7\text{ c} \times 0.5\text{ c}}{c^2}\right)}$$ ***[1]***

$$= \left(\frac{1.2\text{ c}}{1 + 0.35}\right)$$

$$= \left(\frac{1.2}{1.35}\right)\text{c}$$

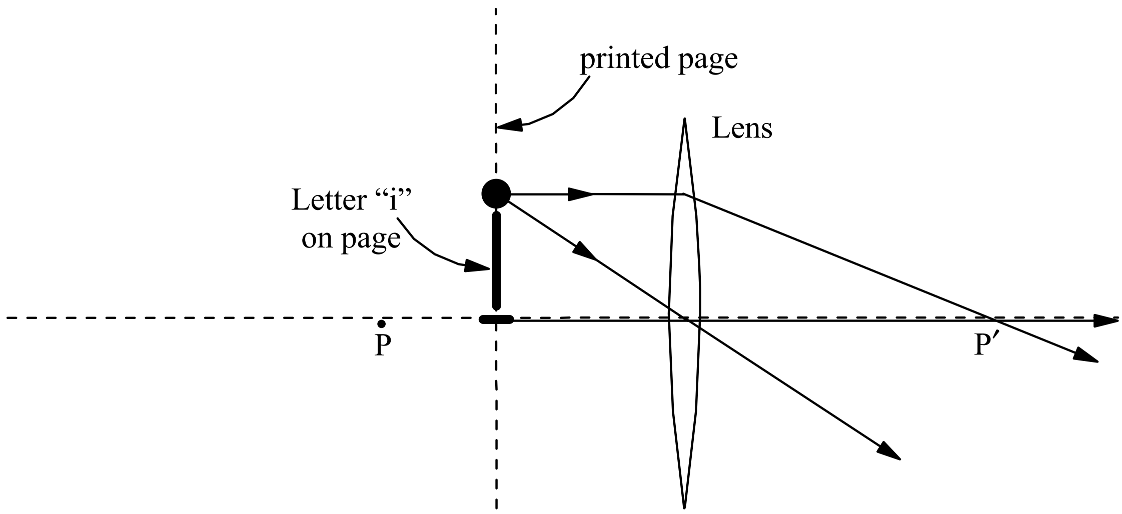
$$= 0.89\text{ c}$$ ***[1]***

*(Essentially **[1]** for knowing the formula to apply, **[1]** for correct substitutions, **[1]** for calculations.)* ***[3]***
[3 max]

(c) $v = v_{\text{electron}} - v_{\text{nucleus}}$ ***[1]***
$0.89\text{ c} - 0.5\text{ c} = 0.39\text{ c}$ ***[1]*** ***[2]***
[2 max]

H1. Images in a convex lens ***[12]***

(a) *Lens close to the page.*



(i) Anywhere to the right of the lens. ***[1]*** ***[1]***
[1 max]

(ii) Right way up.
Enlarged.
Behind the lens.
Further away than the page.
Yes.

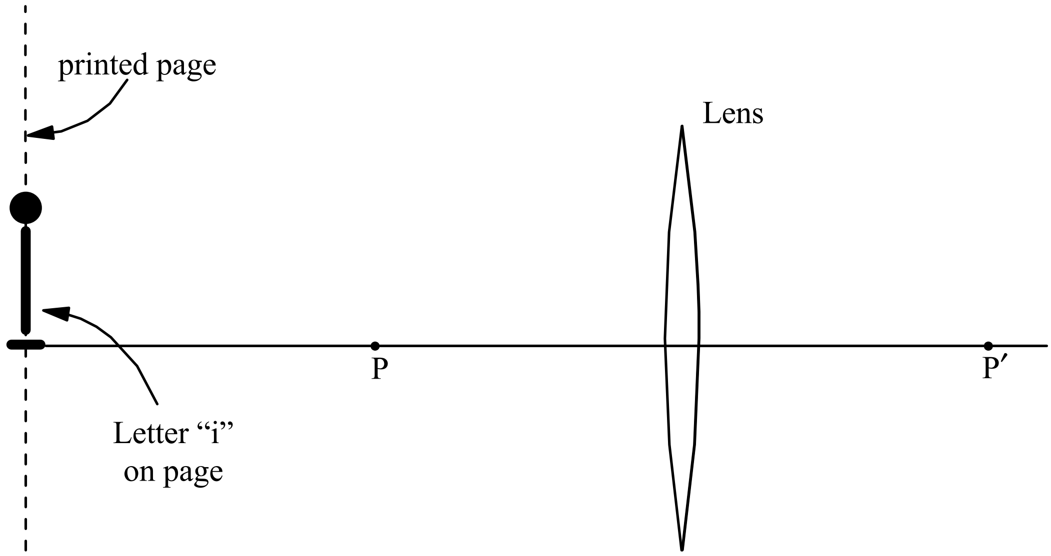
*(Mark as a whole, **[2]** for complete understanding, lose **[1]** per error: 2 errors gets zero.)* ***[2]***
[2 max]

(iii) No. ***[1]*** ***[1]***
[1 max]

continued...

Question H1 continued

(b) *Lens further from the page*



(i) (Image will be located just outside P′.) ***[4]*** ***[4]***
[4 max]

(ii) Eye located to the right of the image. ***[1]*** ***[1]***
[1 max]

(iii) Upside down.
Diminished.
In front of lens.
Nearer to her.
No.

(Mark as a whole, ***[2]*** *for complete understanding, lose* ***[1]*** *per error: 2 errors gets zero.)* ***[2]***
[2 max]

(iv) Yes. ***[1]*** ***[1]***
[1 max]

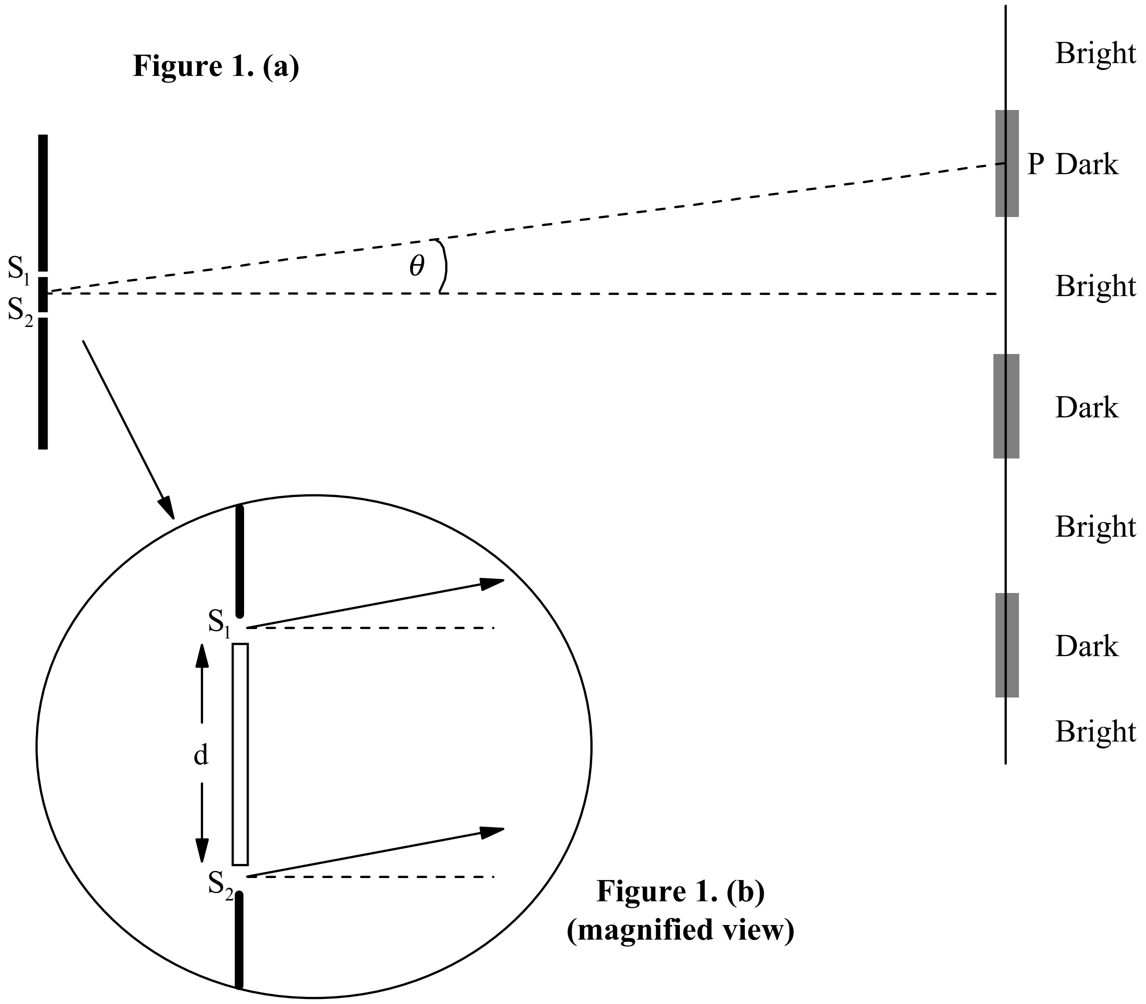
H2. Double-slit interference ***[8]***

(a) Light does arrive from both slits, but out of phase: by half a wavelength because of the path difference. ***[1]***
Crests of one coincide with troughs of the other, giving destructive interference. ***[1]*** ***[2]***
[2 max]

continued...

Question H2 continued

(b)



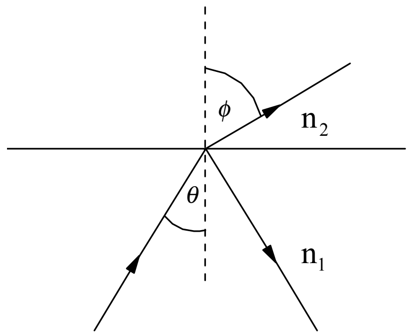
Standard textbook derivation. ***[4]***

By judgement, guided but not bound by the following:
Construction in diagram to show path difference. ***[1]***
Putting path diff $= \frac{\lambda}{2}$ ***[1]***
Expressing path difference in terms of trig of triangle. ***[1]***
Relating angle P to angle of triangle. ***[1]***
Overall conceptual grasp and quality of explanation of steps. ***[1]*** ***[4]***
[4 max]

(c) No, P would not remain dark. ***[1]***
Light from all three arrives at P: light from S_1 and S_2 interferes destructively, leaving an effect due to S_3. ***[1]*** ***[2]***
[2 max]

H3. Optical dipstick ***[10]***

(a) ***[2]***
[2 max]



(b) Derivation:

Snell's law: $n_1 \sin\theta = n_2 \sin\phi$

Critical condition is when $\phi = 0^\circ$ ***[1]***

Thus $n_1 \sin\theta_c = n_2$ ***[1]***

$$\sin\theta_c = \frac{n_2}{n_1}$$

Look for:

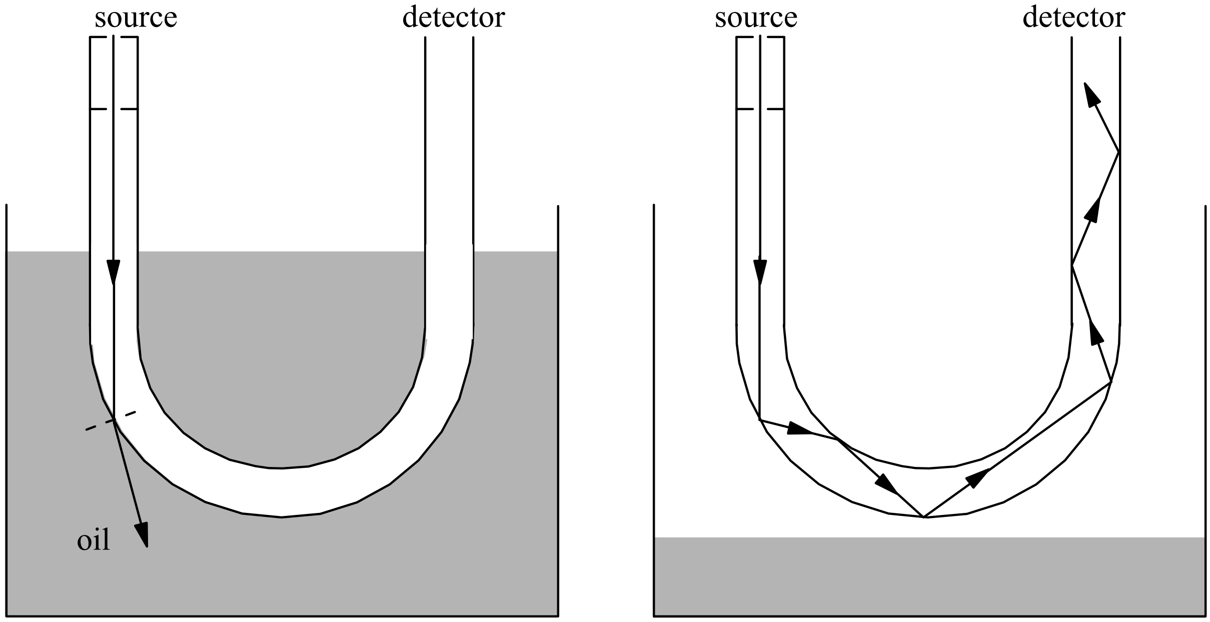
- Put the refracted angle $= 90^\circ$ ***[1]***
- Then Snell's law for this case gives the critical angle condition. ***[1]*** ***[2]***

[2 max]

continued...

Question H3 continued

(c) (i)



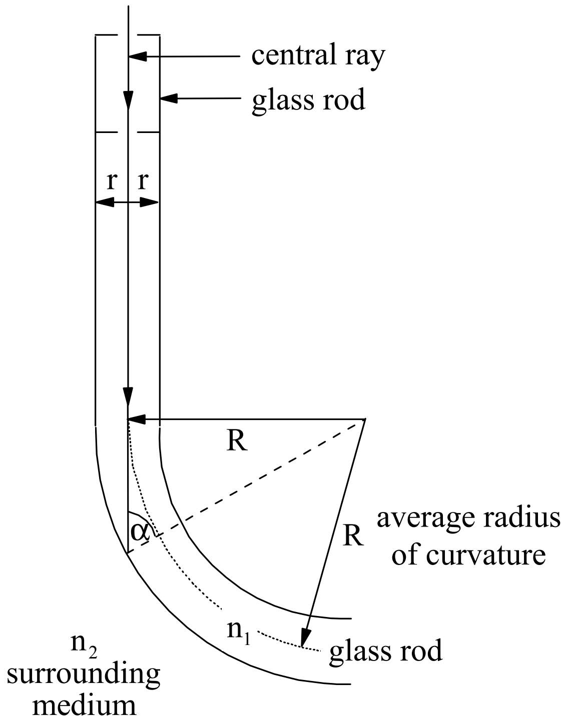
Refraction out of rod for oil, ***[1]*** internal reflection for air. ***[1]*** ***[2]***

[2 max]

(Note: there is a small reflected ray in addition to the refracted ray for the diagram on the left, but do not require it.)

Question H3 (c) continued

(ii)



From geometry of figure,

$$\sin\alpha = \frac{R}{(R+r)} \quad \textbf{\textit{[1]}}$$

The critical angle of incidence is given by $\sin\theta_c = \dfrac{n_2}{n_1}$ ***[1]***

So if α is the critical angle, then

$$\frac{n_2}{n_1} = \frac{R}{(R+r)}, \quad \textbf{\textit{[1]}} \text{ so } \frac{n_2}{n_1}R = R + r \text{ or } R\left(\frac{n_1}{n_2 - 1}\right) = r$$

$$R = \frac{r}{\left(\dfrac{n_1}{n_2 - 1}\right)} \quad \textbf{\textit{[1]}}$$

[4]
[4 max]