INTERNATIONAL BACCALAUREATE
BACCALAURÉAT INTERNATIONAL
BACHILLERATO INTERNACIONAL

PHYSICS
HIGHER LEVEL
PAPER 3

Tuesday 9 May 2000 (morning)

1 hour 15 minutes

Name

Number

INSTRUCTIONS TO CANDIDATES

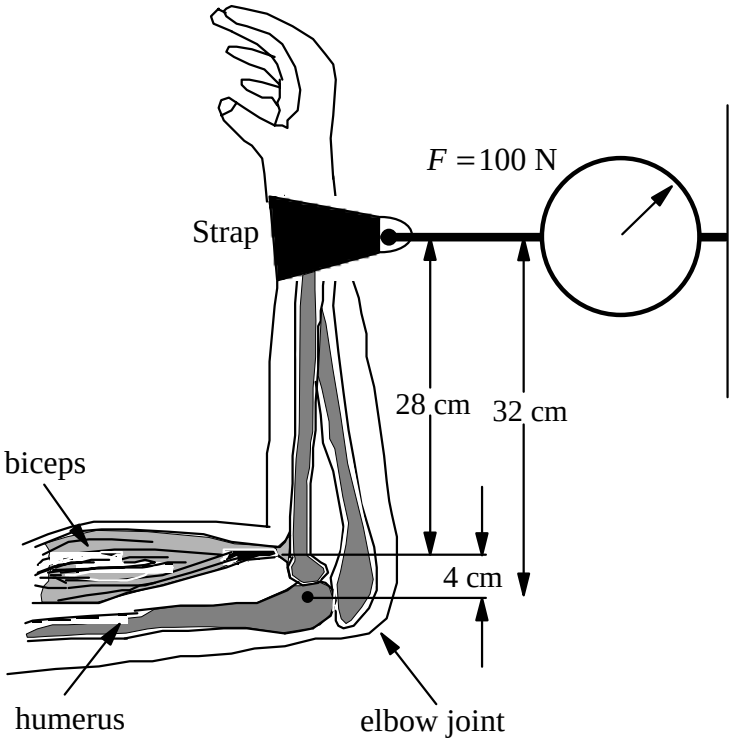
- Write your candidate name and number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all of the questions from two of the Options in the spaces provided.
- At the end of the examination, indicate the letters of the Options answered in the boxes below.

OPTIONS ANSWERED	EXAMINER	TEAM LEADER	IBCA
	/30	/30	/30
	/30	/30	/30
	TOTAL /60	TOTAL /60	TOTAL /60

OPTION D – BIOMEDICAL PHYSICS

D1. Forces in the human arm

The arm pulls against the strap as shown so that the scale reads a force of 100 N.



(a) State in words the **two** conditions for a rigid body to be in equilibrium under the action of a number of forces. *[3]*

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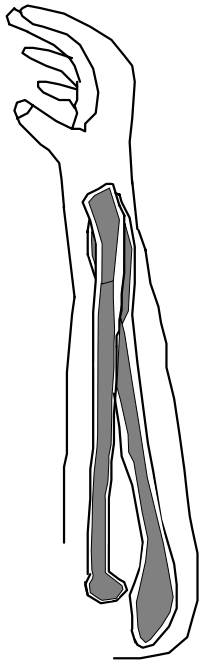
(This question continues on the following page)

(Question D1 continued)

(b) The forearm is redrawn below. On the diagram, draw in force vectors to represent *all* the forces acting *on* the forearm. State what object exerts each force. *[4]*



(c) Calculate the torque about the elbow joint produced on the arm by the strap. Is this torque clockwise or counter clockwise in the diagram? *[2]*

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(d) Will the force exerted by the biceps muscle be greater than, less than or equal to the force exerted by the strap? Explain your reasoning, without calculations. *[1]*

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(e) Calculate the force exerted by the biceps muscle. *[2]*

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(f) Explain why, in this particular situation, the weight of the forearm does not play a role in determining the force exerted by the biceps muscle. *[2]*

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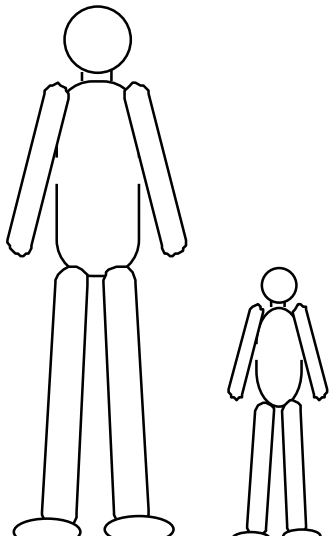
D2. Walking barefoot on gravel

An adult and a child are walking barefoot over rough gravel. The adult is **twice** as tall as the child, and they are of similar shape.



For the adult as compared to the child, determine the following:

(a) The ratio of their masses. *[1]*

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(b) The ratio of the forces on the soles of their feet. *[1]*

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(c) The ratio of the areas of their feet in contact with the ground. *[1]*

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(d) The ratio of the pressures (force per unit area) on the soles of their feet. *[2]*

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(e) Which one is likely to find it more painful walking on the rough gravel, or will it be the same for both? Explain briefly. *[1]*

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D3. Radioactive tracers

A chemical compound containing a radioactive isotope is introduced into a patient as a 'tracer' to study a physiological process. The *radioactive half-life* of the isotope is 3 days, and the *biological half-life* of the chemical compound in the body is 2 days.

(a) Explain the terms:

(i) Radioactive half-life *[2]*

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(ii) Biological half-life *[2]*

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(b) If the activity of the tracer sample introduced into the body was A, determine the activity of that portion of tracer remaining in the body 6 days later. *[4]*

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(c) For physiological studies, explain why it is desirable to use a tracer substance which has a greater radioactive half-life than biological half-life. *[2]*

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OPTION E – HISTORICAL PHYSICS

E1. Models of the universe

The Ptolemaic model of the universe was geocentric while the Copernican model was heliocentric.

(a) *Ptolemaic model*

How did the Ptolemaic model account for the following observations?

(i) The stars move in the sky during the course of the night, while the pattern of stars nevertheless remains unchanged. *[2]*

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(ii) The moon also moves across the sky but at a slightly slower rate than the stars, so that its position relative to the stars changes continually. *[2]*

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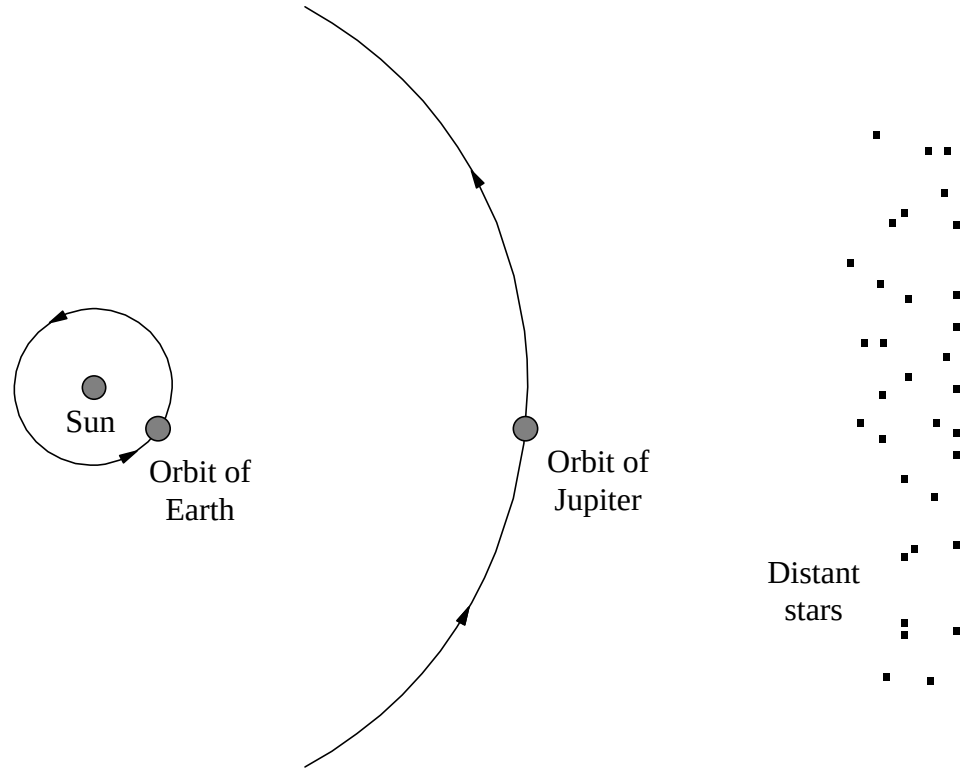
(iii) The 'wandering stars' (planets) move gradually with respect to the stars, and periodically reverse their motions before continuing again. Explain this by sketching suitable planetary cycles and epicycles on the diagram below, and tracing out the resulting motion of a planet. *[3]*

(This question continues on the following page)

(Question E1 continued)

(b) *Copernican model*

On the Copernican (heliocentric) model the planets orbit the sun. The diagram below shows the orbits of the earth and Jupiter around the sun, with the 'fixed' stars in the far distance (not to scale).



The positions of earth and Jupiter at one particular time are as shown. The speed of Jupiter in its orbit is less than **half** that of the earth.

(i) Draw in the approximate position of the earth and Jupiter roughly three months later. *[1]*

(ii) With the aid of constructions on the diagram, explain why Jupiter will exhibit 'retrograde' motion against the background of the stars. *[2]*

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(Question E1 continued)

(c) Kepler found that the Copernican model could account for the observed motion of Jupiter and most of the other planets. However it could not quite match the motion of Mars, to the precision of Tycho Brahe's observations, even using subsidiary cycles. What important break with all previous models did Kepler finally make to account for the motion of Mars? *[2]*

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E2. Cannon boring and caloric

Count Rumford observed the barrels of iron cannons being bored out by cutting tools, producing metal chips. He reported in 1798 that this mechanical process seemed to provide an 'inexhaustible supply of heat'.

(a) How did the 'caloric' theory existing at that time account for the production of heat in the cutting process? *[2]*

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(b) If the boring tool became blunt so that it did not cut as well, what did the caloric theory predict would happen to the rate of heat production, and why? Was this observed? *[2]*

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(c) Why was the observation that the supply of heat seemed 'inexhaustible' a problem for the caloric theory? *[2]*

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(d) What new idea did Rumford propose to account for the production of heat in this process? *[2]*

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E3. Virtual particles and forces

(a) Explain what is meant by a virtual particle. *[2]*

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(b) Describe how the electrostatic repulsion between two like charges (Coulomb force) can be explained in terms of the exchange of virtual photons. *[3]*

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(c) Complete the following table, listing the **four** fundamental forces, giving the exchange particles and characterising the ranges. *[5]*

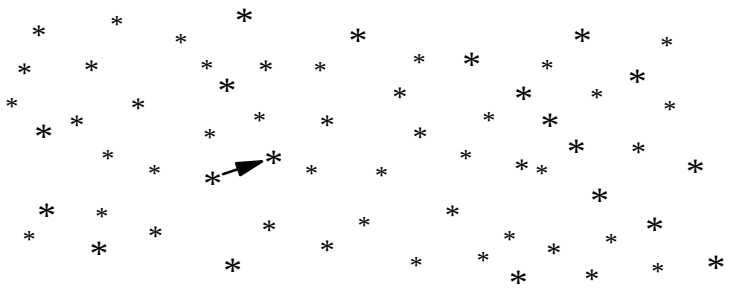
	Force	Exchange particle	Range of force (infinite or short range)
1.	. . . . .	graviton	. . . . .
2.	Electromagnetic	photon	. . . . .
3.	. . . . .	$W^{\pm}$, Z^0	. . . . .
4.	. . . . .	. . . . . .	. . . . .

OPTION F – ASTROPHYSICS

F1. Stellar distances

This question is about determining the distance to a nearby star.

Two photographs of an area of the night sky are taken through a telescope from earth, one six months after the other. Comparing the photographs, one star seems to have shifted slightly relative to the other stars, as shown in the figure. (The figure is made up of the two photographs overlapping.)



(a) What can we deduce from the fact that one star appears displaced against the others? *[1]*

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(b) If the observed angular displacement of a star is θ and the diameter of the earth's orbit is d, show with the aid of a diagram that the distance D to the star is given approximately by the formula $D \approx d / \theta$, if θ is small and measured in radians. *[4]*

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(c) Why can Hubble's law not be used to determine the distance to the star? For what objects in the universe can Hubble's law be used to determine distance? *[3]*

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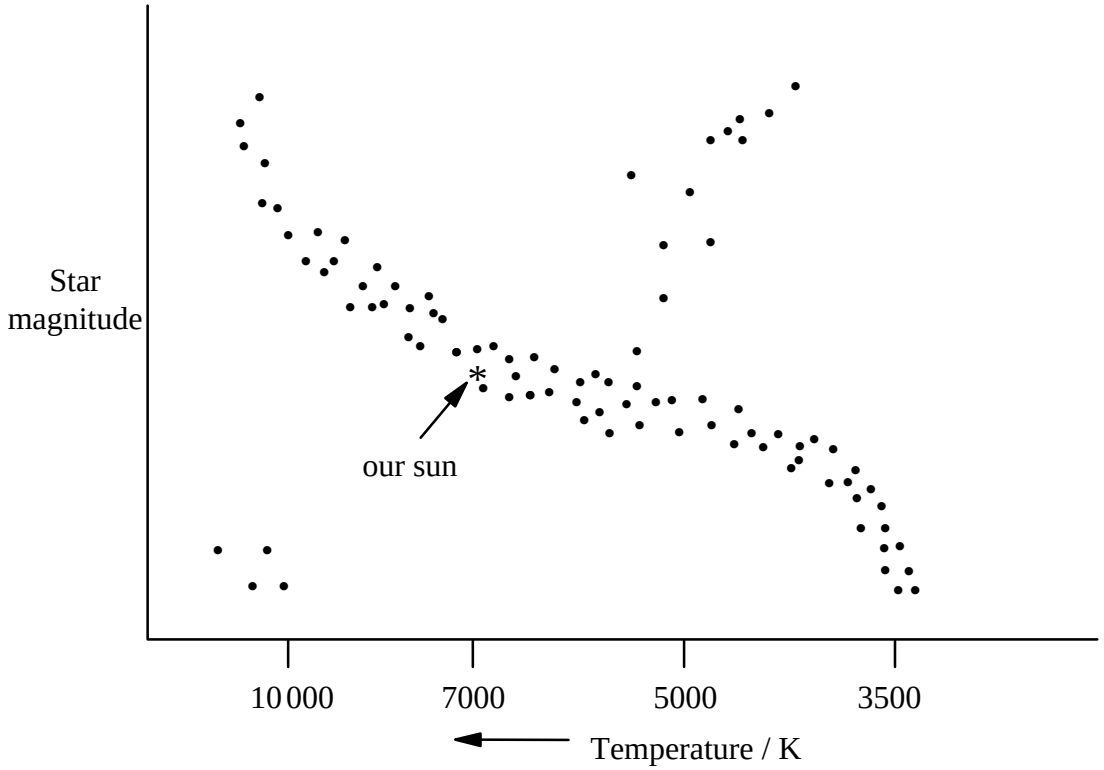
F2. Hertzsprung-Russell diagram

A Hertzsprung-Russell (H-R) diagram is shown in the figure below.



(a) The vertical axis gives 'star magnitude'. Must this be the *apparent* (observed) magnitude or *absolute* magnitude? Explain why. *[2]*

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(b) On the H-R diagram, why do we choose to use a *logarithmic* scale for star magnitudes rather than a linear scale? *[2]*

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(c) The horizontal axis of the H-R diagram gives star temperature. Is this the *interior* temperature or the *surface* temperature of the star? Explain why. *[2]*

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(Question F2 continued)

(d) How are the values for star temperatures obtained from the earth? Outline a possible procedure. *[2]*

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(e) Consider a star of similar age to our own sun but of greater mass.

(i) How would the *luminosity* and the *colour* of this more massive star compare with those of our sun? Explain your reasoning briefly. *[3]*

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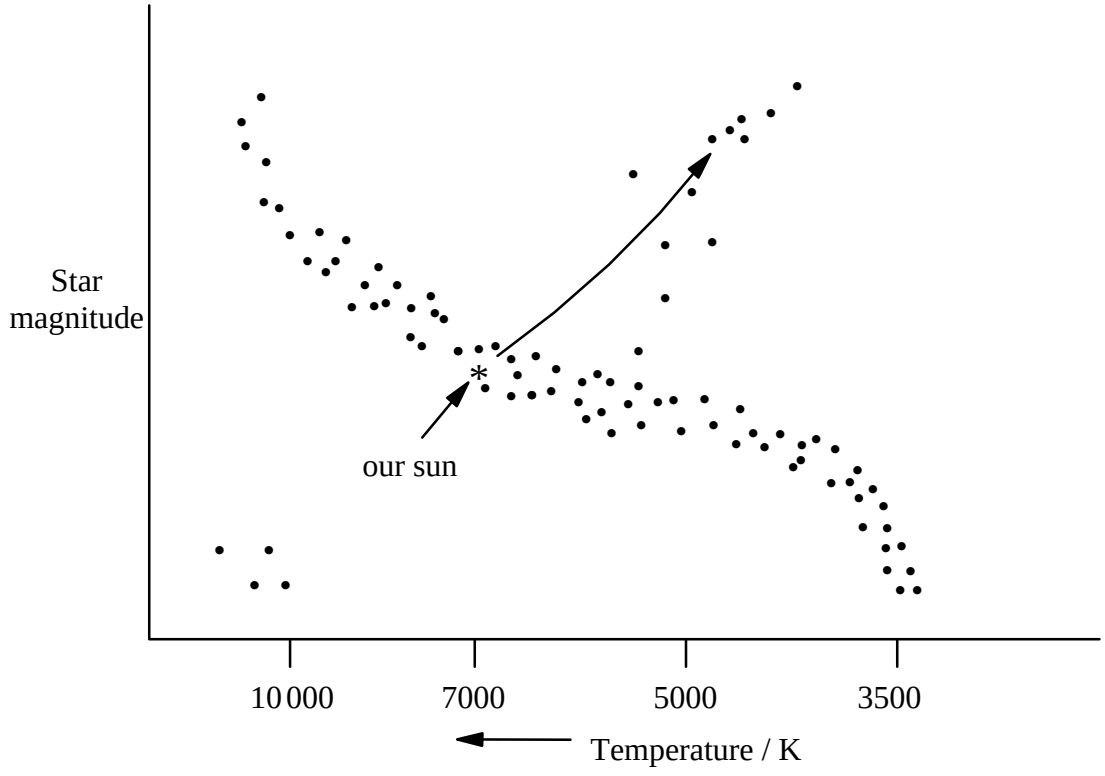
(ii) The position of our own sun on the H-R diagram is marked. Where on the diagram, relative to the sun, would the more massive star be located? Mark and label the region where it might occur. *[1]*



(This question continues on the following page)

(Question F2 continued)

(f) Our sun will remain on the main sequence of the H-R diagram for about another 5 billion years, and will then become a red giant, following the evolutionary path shown on the previous page.

(i) Explain why the sun will leave the main sequence, and describe the processes that occur as it becomes a red giant. *[4]*

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(ii) When the sun is in the 'red giant' stage, why will it be redder and more luminous than it is now? *[2]*

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(iii) After the red giant stage the sun will evolve further. On the H-R diagram on the previous page trace the evolutionary path it will follow. *[1]*

(iv) What will be the eventual fate of our sun? Describe what it will be like. *[3]*

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OPTION G – SPECIAL AND GENERAL RELATIVITY

G1. Relativity and simultaneity

(a) State the **two** postulates of the special theory of relativity. *[2]*

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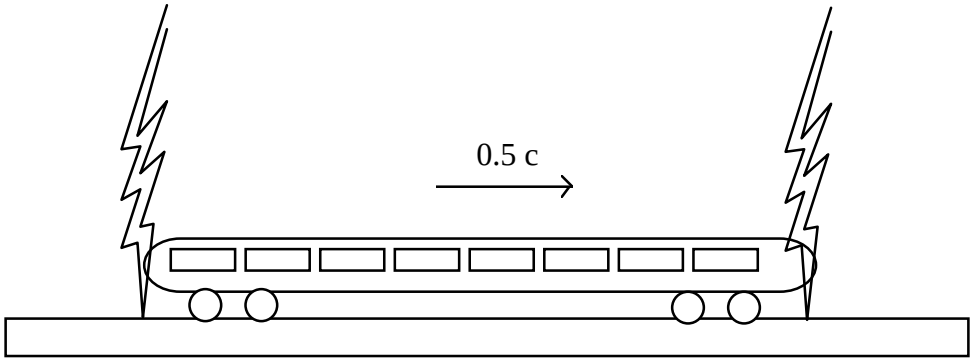
Einstein proposed a 'thought experiment' along the following lines. Imagine a train of proper length 100 m passing through a station at half the speed of light. There are two lightning strikes, one at the front and one at the rear of the train, leaving scorch marks on both the train and the station platform. Observer S is standing on the station platform midway between the two strikes, while observer T is sitting in the middle of the train. Light from each strike travels to both observers.



(b) If observer S on the station concludes from his observations that the two lightning strikes occurred simultaneously, explain why observer T on the train will conclude that they did **not** occur simultaneously. *[4]*

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(This question continues on the following page)

(Question G1 continued)

(c) Which strike will T conclude occurred first? *[1]*

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(d) What will be the distance between the scorch marks on the *train*, according to T and according to S? *[3]*

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(e) What will be the distance between the scorch marks on the *platform*, according to T and according to S? *[2]*

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G2. Space capsule

Two space travellers Lee and Anna are put into a state of hibernation in a ventilated capsule in a spaceship, for a long trip to find another habitable planet. They eventually awake, but do not know whether the ship is still travelling or whether they have landed. They feel attracted toward the floor of the capsule, an experience rather like weak gravity. Lee says the spaceship must have landed on a planet and they are experiencing its gravitational attraction. Anna says the spaceship must be accelerating and the capsule floor is pushing on them.

(a) Hoping to decide which of them is right, they try an experiment. They release a hammer in mid air, and it accelerates straight to the floor. Does this observation help them decide? How would *each* of them explain the motion of the hammer? *[4]*

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(b) They propose another experiment, namely to shine monochromatic light from the floor to the ceiling of the capsule and use sensitive apparatus to detect any change in frequency.

(i) How would Lee explain how a redshift arises, viewing the radiation as photons moving in a gravitational field? *[2]*

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(ii) How would Anna explain how a redshift arises, viewing the radiation in terms of wavefronts arriving at a detector whose speed is increasing? *[2]*

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(c) Can Lee and Anna perform *any* experiment in the capsule which could distinguish whether they are on the surface of a planet or accelerating in space? . . . . . .

State why: . . . . . *[1]*

(This question continues on the following page)

(Question G2 continued)

(d) Later they notice that the gravitational-like sensation starts diminishing gradually, until they eventually 'float weightless' in the capsule. Lee suggests that they must have taken off from the planet, and as they got further away its gravitational attraction diminished until it was negligible. Anna suggests that the spaceship must have gradually reduced its thrust and acceleration to zero. Which explanation is feasible, or is there no way to tell who is right? Explain. *[3]*

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G3. Decay in flight

An unstable nucleus is moving with velocity 0.5 c relative to the laboratory. While moving it decays by emitting an electron in the same direction of travel as the nucleus, at a speed of 0.7 c relative to the nucleus.

(a) If one attempted to use Galilean kinematics, what speed would be predicted for the electron relative to the laboratory? *[1]*

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(b) Using relativistic kinematics, calculate the speed of the electron as measured in the laboratory frame. *[3]*

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(c) Viewed from the laboratory frame, how much faster is the electron travelling than the nucleus? *[2]*

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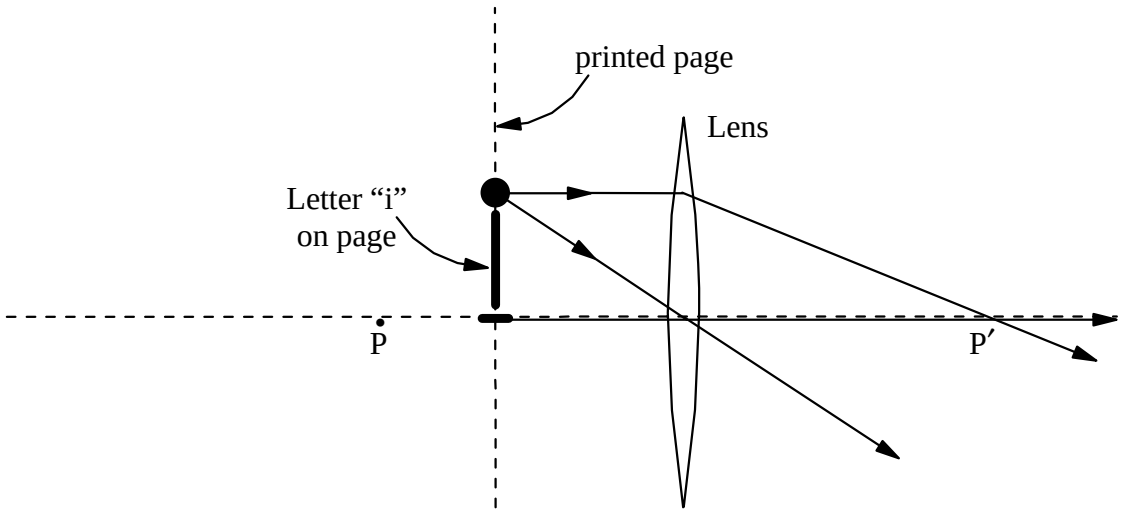
OPTION H – OPTICS

H1. Images in a convex lens

An elderly lady buys a ‘magnifying glass’ to read small print in the telephone directory. To her surprise she finds that if she holds the convex lens fairly close to the page she gets one kind of image, while if she holds it fairly far from the page she gets quite another kind of image. Having studied physics long ago, she wishes to understand this using ray diagrams.

(a) *Lens close to the page*

For the lens quite close to the page she draws the ray diagram below.



(i) Where should her eye be located in order to see the image of the letter “i”? Tick the correct answer below. *[1]*

To the left of the lens	☐
Anywhere to the right of the lens	☐
To the right of the focal point P′	☐

(ii) If she looks at letters on a page in this way, how will they appear to her? *[2]*

Right way up or upside down? . . . . . .

Enlarged or diminished? . . . . . .

Behind the lens or in front of the lens? . . . . . .

Should she be able to read the telephone directory using the lens this way? . . . . . .

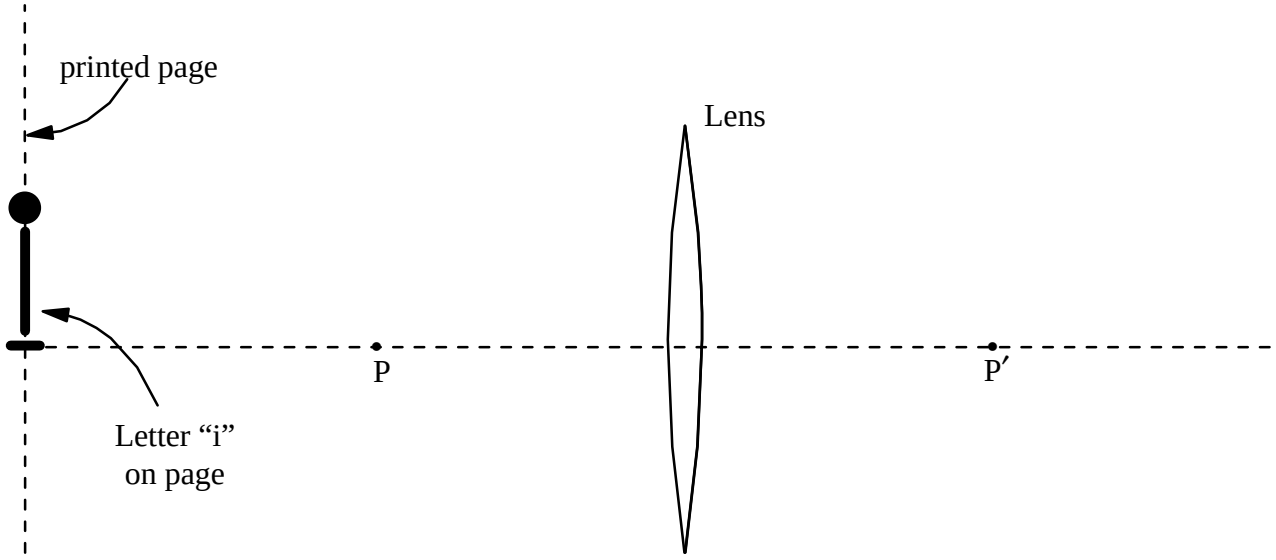
(iii) Instead of looking through the lens to see the image, could she ‘capture’ it by placing a screen or film at the image location? . . . . . *[1]*

(This question continues on the following page)

(Question H1 continued)

(b) *Lens further from the page*

The lady now moves the page further from the lens. The diagram below represents the situation where the page is more than twice the focal distance from the lens.



(i) Locate the image of the "i" by tracing suitable rays on the diagram. *[4]*

(ii) Where should the lady's eye be located in order to see the image? Tick the correct answer below. *[1]*

To the left of the lens	☐
Anywhere to the right of the lens	☐
Between the lens and P′	☐
To the right of the image	☐

(iii) If she looks at letters on a page in this way, how will they appear to her? *[2]*

Right way up or upside down? . . . . . .

Enlarged or diminished? . . . . . .

Behind the lens or in front of the lens? . . . . . .

Nearer or further away than the page? . . . . . .

Will she be able to read the telephone directory using the lens this way? . . . . . .

(iv) Instead of looking through the lens to see the image, could she 'capture' it placing a screen or film at the image location? . . . . . *[1]*

H2. Double-slit interference

In a classroom demonstration, laser light is shone onto two narrow slits S_1 and S_2 in a dark room, and an interference pattern of bright and dark lines (fringes) appears on a screen, as shown in the figure below. (The fringe spacing is exaggerated for clarity.)

(a) A fellow student asks you: "How can it be *dark* at point P? After all, light must be arriving there from both slits".
Is the student correct that light is arriving at point P from both slits? . . . . . .

How would you explain to the student why it is dark at point P? *[2]*

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(This question continues on the following page)

(Question H2 continued)

(b) The situation is shown again in **Figure 1. (a)** below, and a 'magnified' view of the slit region is shown in the circle in **Figure 1. (b)**.

Figure 1. (a)

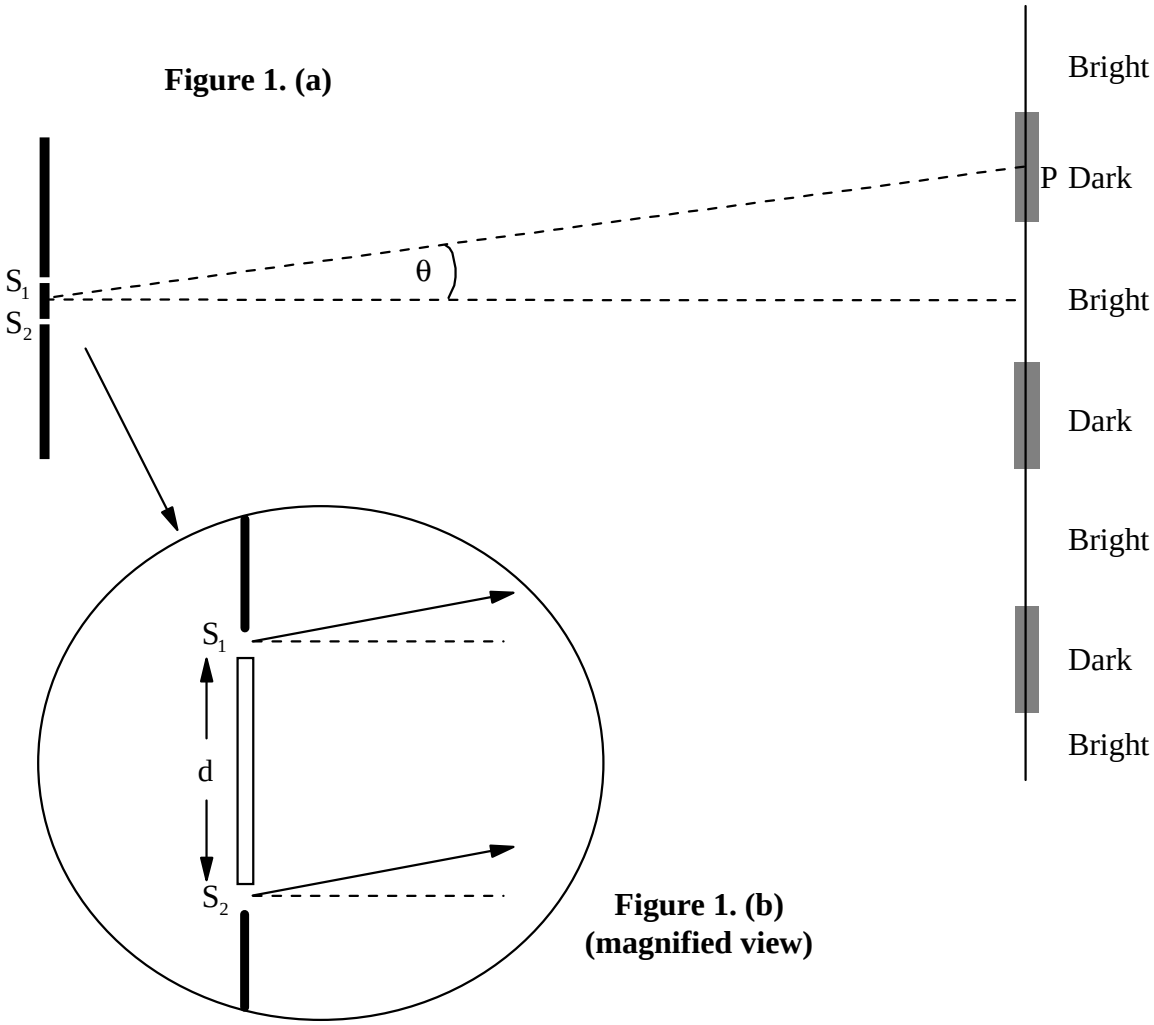

Figure 1. (b)
(magnified view)

Show that the angle θ at which the first **dark** fringe P occurs is given by the expression $\sin\theta = \lambda / 2d$, where λ is the wavelength of the light. Assume the screen is far away. Draw and label any construction needed on **Figures 1. (a)** and **1. (b)**, and explain the steps in your derivation. *[4]*

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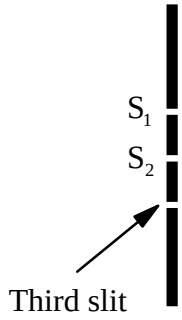
(Question H2 continued)

(c) Suppose a third slit were opened an equal distance below S_2, as shown.



Would point P on the screen remain dark, or not? Explain. *[2]*

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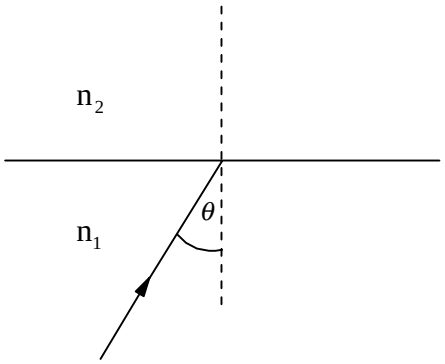
H3. Optical dipstick

This question is about total internal reflection of light and a practical application.

(a) The diagram below shows light incident on the interface between two transparent media of refractive indices n_1 and n_2. In general the light will be partly reflected and partly refracted. Sketch in the reflected and refracted rays, for the case $n_2 < n_1$. *[2]*



(b) Show that the critical angle of incidence θ_c for total internal reflection of the light is given by the expression $\sin\theta_c = \frac{n_2}{n_1}$. *[2]*

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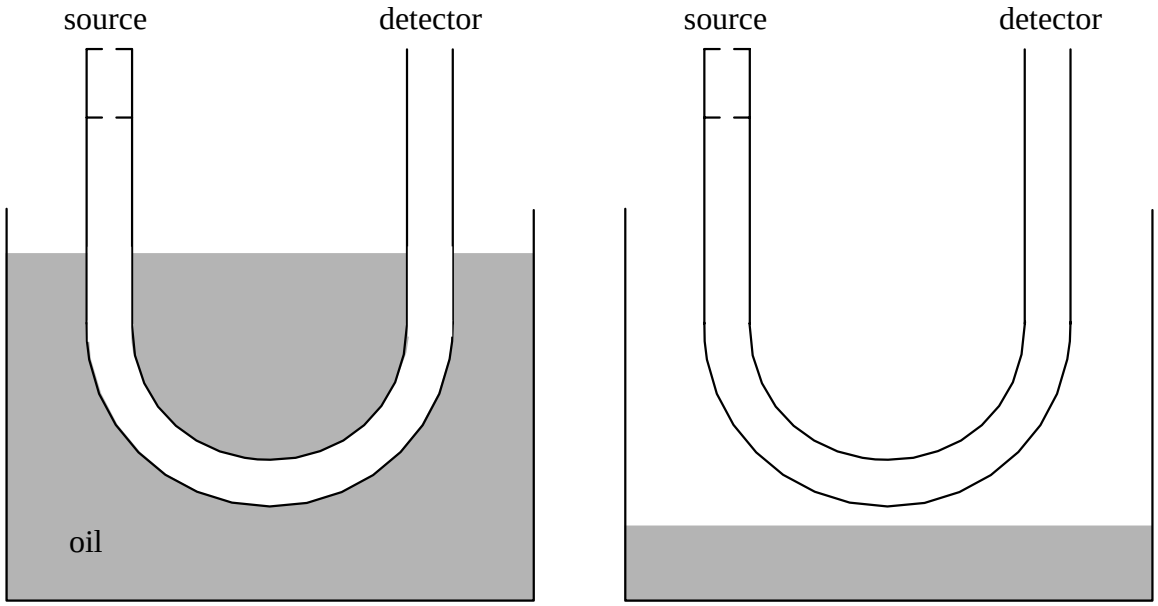
(This question continues on the following page)

(Question H3 continued)

(c) The figures below show an 'optical dipstick' used to warn if the level of oil in a storage tank drops too low. A glass rod is bent into a curved U-section as shown. Light enters at one end of the rod and there is a light detector at the other end. Normally the U-section is immersed in oil but if the level drops too low the section is exposed to air. The refractive indices of glass, oil and air are 1.5, 1.3 and 1.0 respectively.

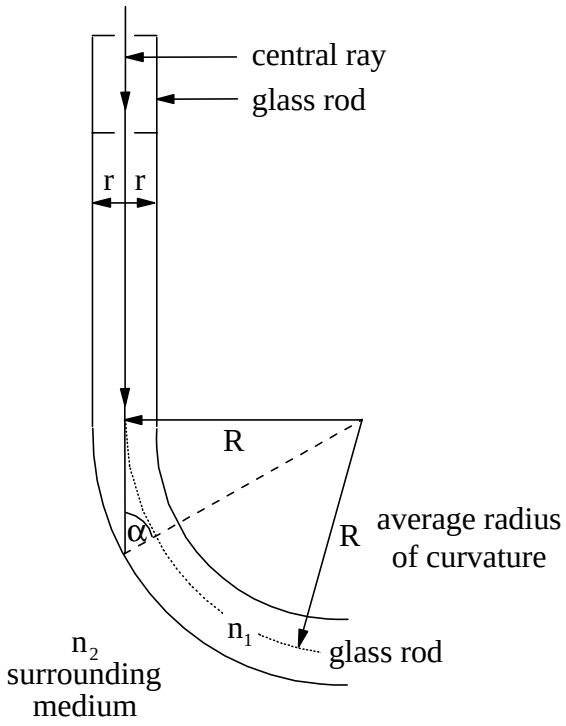


(i) By completing the diagrams above, illustrate how light is totally internally reflected around the bend in one case and not in the other. Sketch the paths of the light rays in each case. *[2]*

(This question continues on the following page)

(Question H3 (c) continued)

(ii) The figure below shows a ray entering a glass rod of radius r and radius of curvature R. The refractive index of the glass is n_1 and that of the surrounding medium is n_2. The central ray strikes the side of the rod at an angle α as shown.



The radius of curvature R of the bend cannot be less than a certain minimum value or total internal reflection will not occur. Show that the minimum bend radius R is related to the rod radius r and the refractive indices n_1 and n_2 by the equation

$$R = \frac{r}{\frac{n_1}{n_2} - 1}.$$ *[4]*

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