INTERNATIONAL BACCALAUREATE
BACCALAURÉAT INTERNATIONAL
BACHILLERATO INTERNACIONAL

**PHYSICS**
**STANDARD LEVEL**
**PAPER 3**

Tuesday 9 May 2000 (morning)

1 hour

Name

Number

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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 |
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| | /20 | /20 | /20 |
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| | TOTAL /40 | TOTAL /40 | TOTAL /40 |

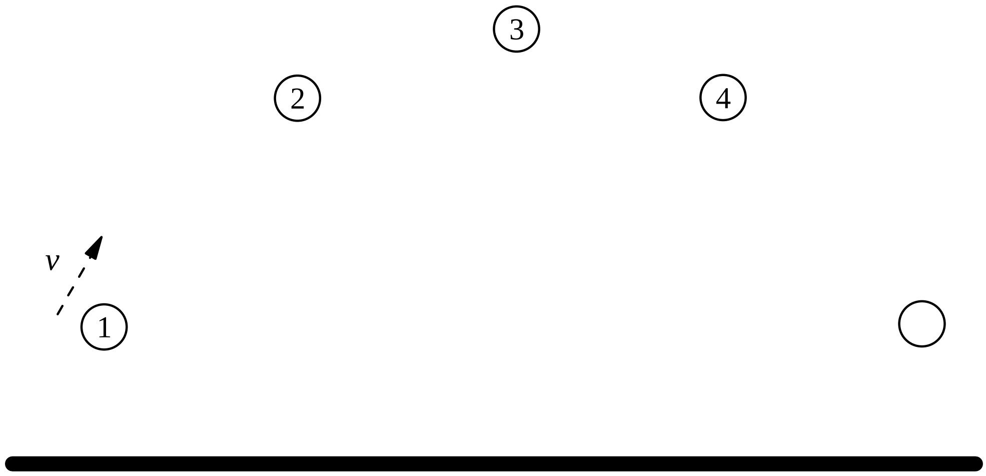
## OPTION A – MECHANICS EXTENSION

### A1. Forces and motions

This question is about the forces on objects undergoing different types of motion.

Two types of motion are shown in the figures below. Successive positions of an object are shown at equally spaced time intervals labelled 1, 2, 3 and 4. The velocity at the first position is shown as an arrow labelled ***v***. In each case, draw in vectors to show the **force(s)** acting on the object in the labelled positions. Pay attention to both direction and magnitude. Name the source(s) of the force(s) and answer the questions on energy.

(a) *Projectile motion*. Assume air resistance is negligible. *[3]*




Draw in force vectors in the diagram above.

Name the source(s) exerting the force(s). . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

Is energy transformation occurring or not? . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

If so, between what forms of energy? . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

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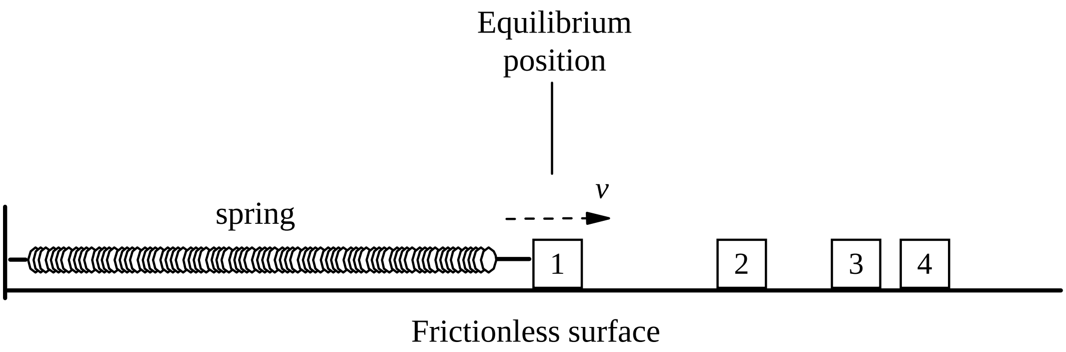
*(This question continues on the following page)*

*(Question A1 continued)*

(b) *Simple harmonic motion on a smooth surface.* Neglect all friction. *[5]*




Draw in all force vectors in the diagram above.

Name the source(s) exerting the force(s). . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

Is energy transformation occurring or not? . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

If so, between what forms of energy? . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

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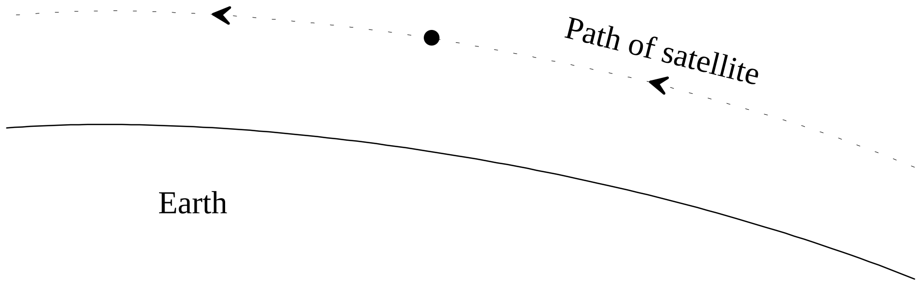
**A2. Satellite**

One evening you observe a point of light moving steadily across the sky and tell your friends it is a satellite. One of them asks how long it will take to go around the earth and come into view again. Being a physics student, you work it out from first principles, explaining as you go. Having no pen or paper you estimate values mentally to one or two significant digits.

(a) *Orbit and force.* The diagram below shows the satellite moving in orbit around the earth. Show and label any forces acting on the satellite at the position shown. State what exerts the force(s). *[2]*




Force(s) on satellite exerted by . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

(b) *Orbit radius.* You know that 'low orbit' satellites are in nearly circular orbits a few hundred kilometres above the earth's surface. You do not remember the radius of the earth but recall that historically the metre was defined so that the distance along the arc between the equator and the pole of the earth was 10 000 kilometres. Show that the radius of the satellite's orbit is approximately $6\times10^6$ m (to one significant digit). *[2]*

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*(This question continues on the following page)*

*(Question A2 continued)*

(c) *Satellite's acceleration.* You decide to take the acceleration of the satellite in its orbit as the same as the gravitational acceleration of a stone dropped near the surface of the earth, *i.e.* approximately 10 $m\,s^{-2}$. Justify why this is a good assumption, even though the satellite

(i) is not at the surface of the earth but several hundred kilometres up;

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(ii) is of different mass to the stone. *[4]*

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(d) *Satellite speed.* Using the estimates above, estimate the speed of the satellite. *[2]*

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(e) *Orbital period.* Hence answer your friend's question: how long will it be before the satellite comes around again? Answer in minutes. *[2]*

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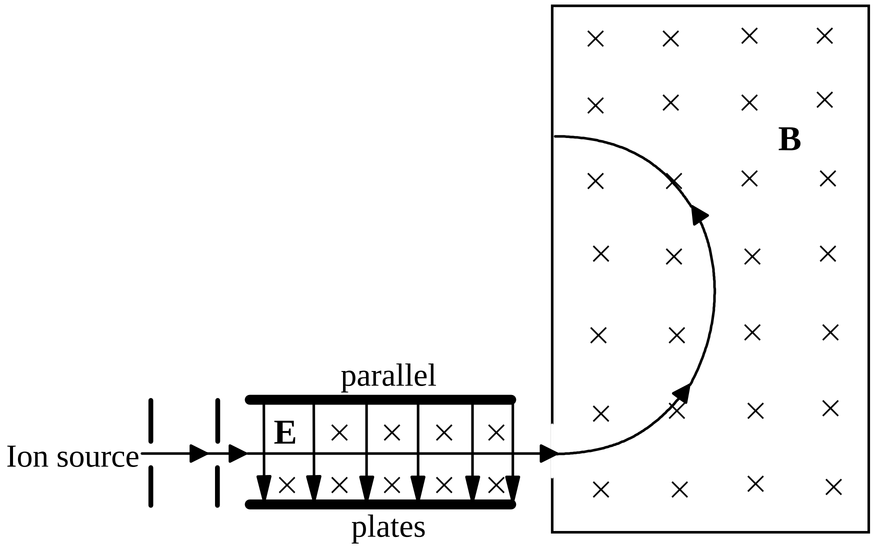
## OPTION B – ATOMIC AND NUCLEAR PHYSICS EXTENSION

**B1. Nuclear masses and the neutron**

In 1911 Rutherford proposed that atoms consisted of a tiny positive nucleus surrounded by electrons, with the nucleus carrying virtually all the mass. This 'nuclear' model sparked investigations of the properties of nuclei, such as those below.

(a) The masses of various nuclei were measured using mass spectrometers. A diagram of a Bainbridge-type mass spectrometer is given below, with the path of a carbon ion drawn in.




**Mass Spectrometer**

(i) What is the *function* of the crossed electric and magnetic fields in the section between the parallel plates, and why is this necessary? *[2]*

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(ii) Consider the passage of another ion, more massive than carbon, but with the same charge and velocity. By considering the dynamics of the ion just after it enters the chamber, explain why it will proceed to take a different path from the carbon ion.

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On the spectrometer diagram above, draw in the path that the more massive ion would take. *[4]*

*(This question continues on the following page)*

*(Question B1 continued)*

(b) To account for the measured masses of nuclei, Rutherford further proposed in 1920 that besides positive particles (protons) there must also be neutral particles in the nucleus. Suggest what aspect of the data on nuclear masses leads one to this conclusion. *[2]*

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(c) In 1932 Chadwick discovered such a neutral particle, the neutron, an achievement for which he was awarded the Nobel prize.

(i) Chadwick produced an ‘unknown radiation’ by bombarding a beryllium target with alpha particles. The nuclear reaction is given below. Complete the details of the reaction products. *[1]*

$${}^{9}_{4}\text{Be} + {}^{4}_{2}\text{He} = \quad \text{C} \quad + \quad \text{n}$$

(ii) Chadwick then detected the neutrons indirectly, by using a paraffin sheet in front of an ionization chamber. Explain how this arrangement allowed neutrons to be detected. *[2]*

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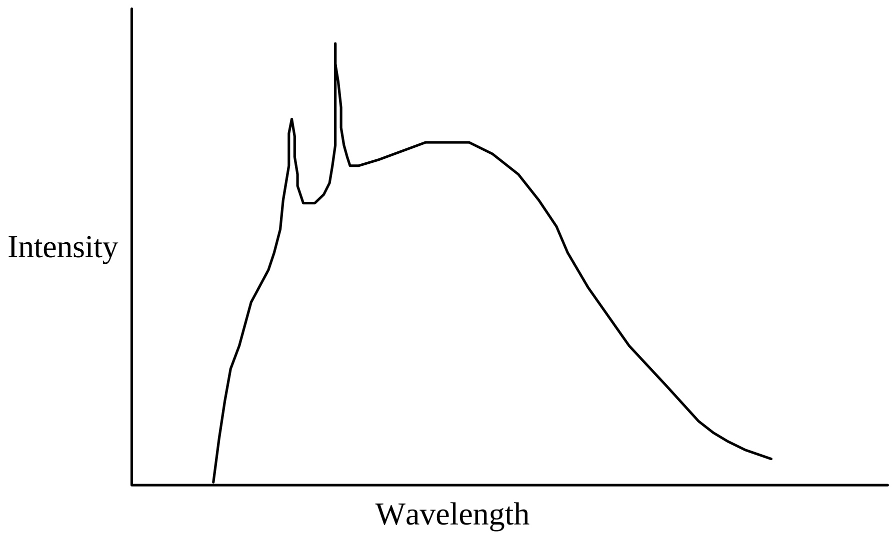
**B2. Production of Bremsstrahlung**

A typical spectrum of X-rays produced when a beam of electrons strikes a metal target is shown below.




(a) Describe the mechanism of production of the **continuous** part of the X-ray spectrum (bremsstrahlung). Your answer should make it clear why X-rays of many wavelengths are produced. *[3]*

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(b) Explain the existence of a ‘cut-off’ wavelength, below which no X-rays are produced. *[2]*

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(c) Determine the minimum wavelength of X-rays produced in an X-ray tube whose operating voltage is 25 kV. Derive any formula you use for this wavelength. *[4]*

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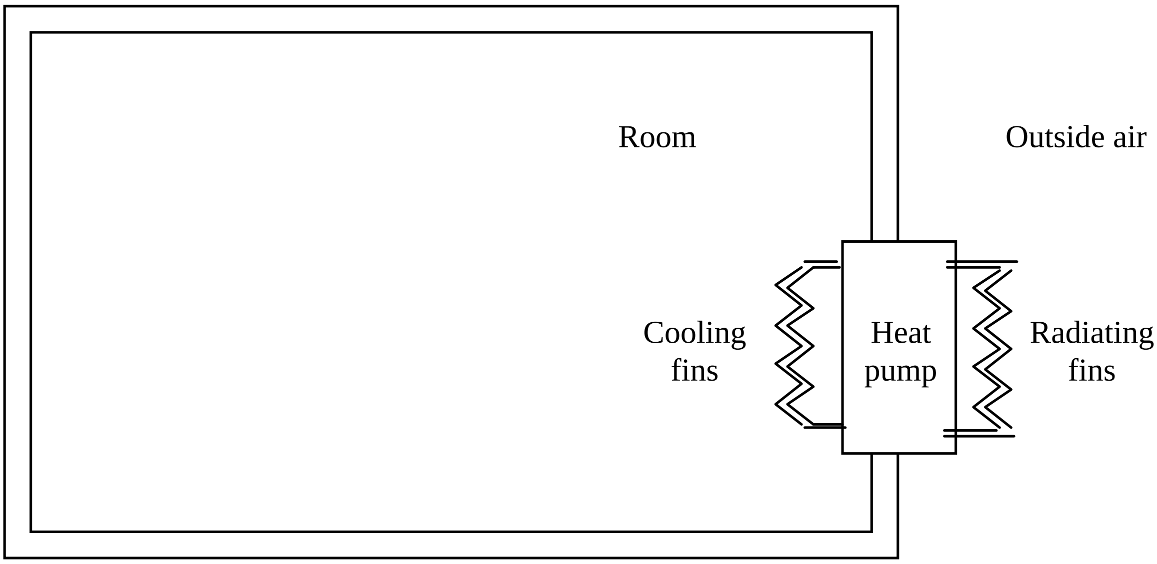
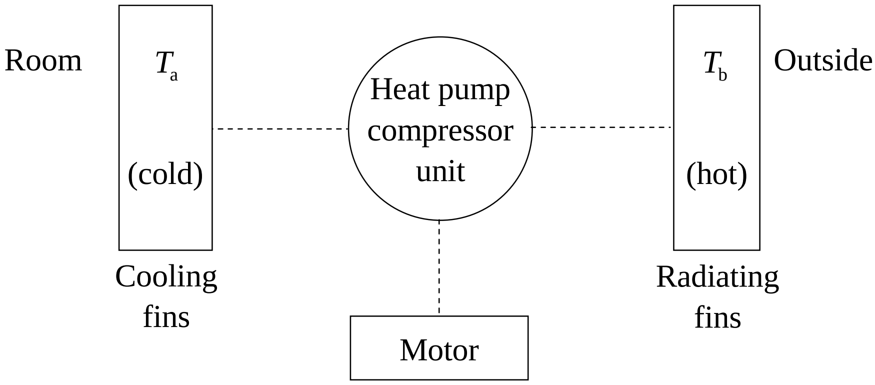
## OPTION C – ENERGY EXTENSION

**C1. Air conditioner**

The figure below shows an air conditioner used to cool a room in summer. It is essentially a 'heat pump' which extracts thermal energy from the room and ejects thermal energy to the air outside.




A schematic diagram of the heat pump and heat transfer fins is shown below.




(a) The dotted lines in the diagram show routes of possible energy flow. Complete the diagram by drawing in labelled arrows representing the energy flows (both heat and work). Use thicker arrows for greater energy flows. *[2]*

(b) Write down an equation which specifies how your labelled energy flows are related. *[1]*

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*(This question continues on the following page)*

*(Question C1 continued)*

(c) Is it possible for an air conditioner to remove more energy per unit time from a room than the electrical power supplied to the unit? Discuss briefly. *[2]*

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(d) Suppose the air conditioner runs with its inside cooling fins at 7 $^{\circ}$C and its outside fins at 47 $^{\circ}$C, and the motor provides 500 W of power. What is the maximum rate of energy extraction from the room? Assume that the ratio of heat flows for the cold and hot reservoirs is the same as the ratio of their absolute temperatures. *[4]*

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(e) The air conditioner results in thermal energy being transferred from a colder region to a warmer region. Is this not contrary to the second law of thermodynamics? Discuss. *[2]*

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**C2. Solar energy**

Explain how solar energy is converted directly into electrical energy in a photovoltaic device. (Describe the nature of the material, the processes that occur and how the potential difference and current arise.) *[5]*

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**C3. Energy crisis**

If energy is always conserved, how can there be an ‘energy crisis’? Why should we worry about ‘using up’ resources? Illustrate your answer with **one** example. *[4]*

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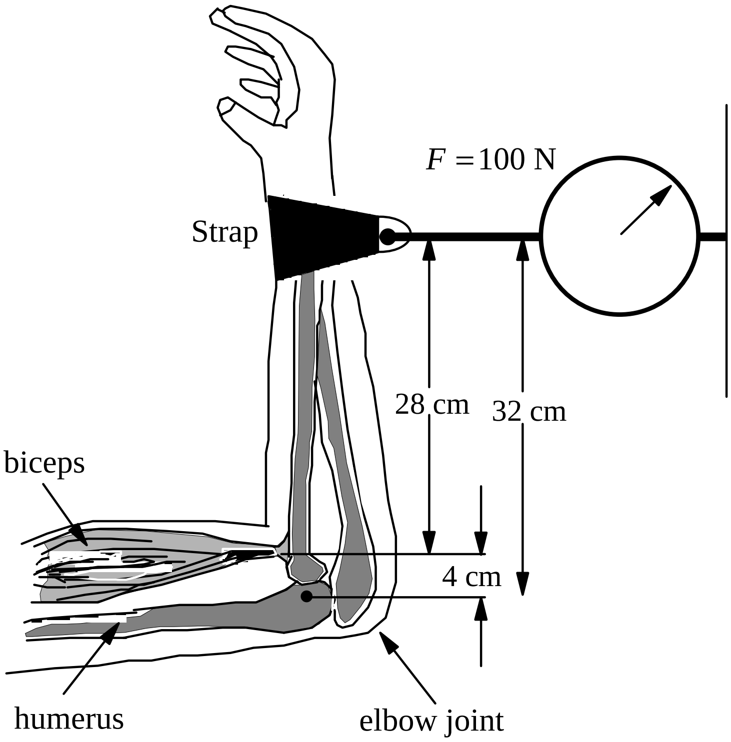
**OPTION D – BIOMEDICAL PHYSICS**

**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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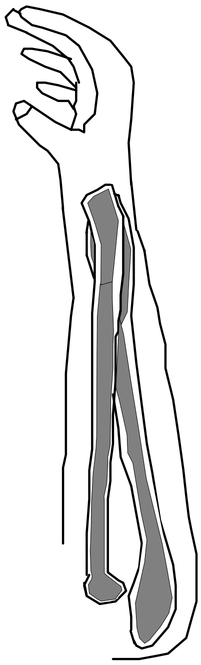
*(This question continues on the following page)*

*(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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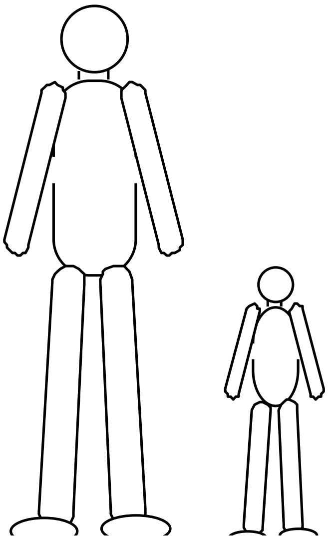
**D2. Walking barefoot on gravel**

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]*

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

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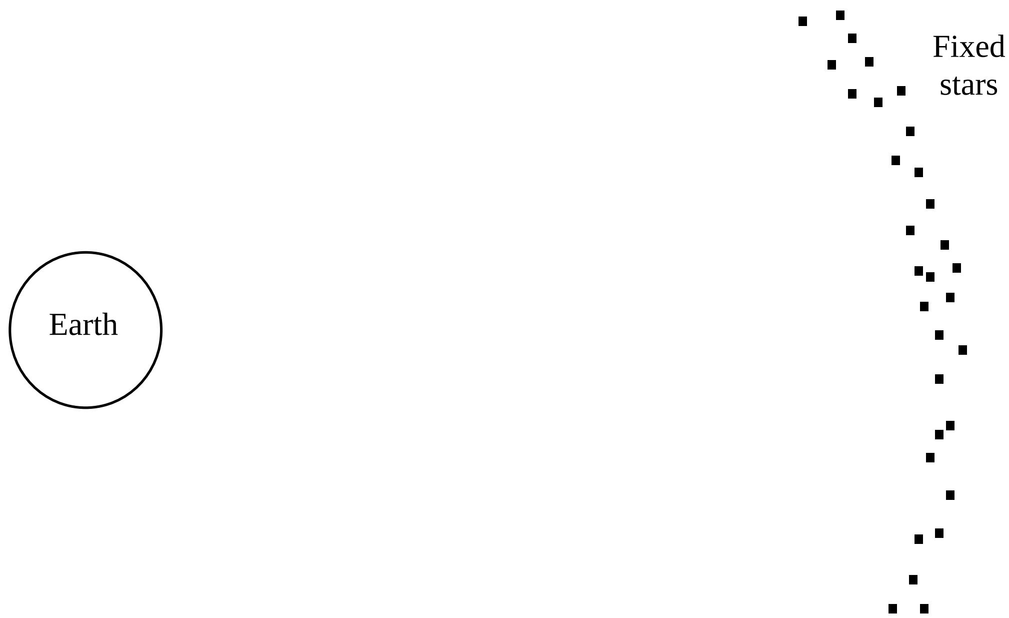
(iii) The 'wandering stars' (planets) move gradually with respect to the stars, and periodically reverse their motions before continuing again. Explain this by sketching suitable planetary cycles and epicycles on the diagram below, and tracing out the resulting motion of a planet. *[3]*

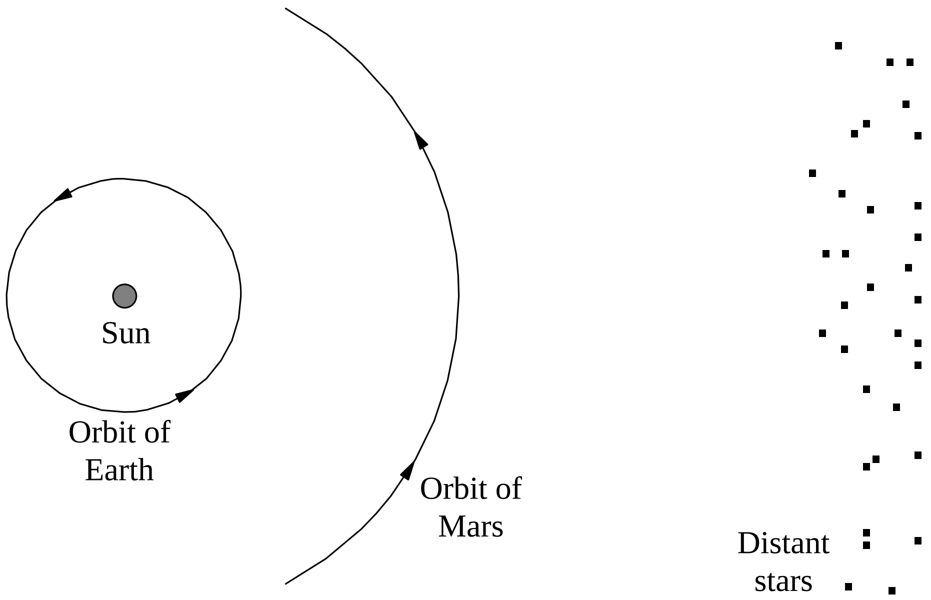



*(This question continues on the following page)*

*(Question E1 continued)*

(b) *Copernican model*

How did the Copernican (heliocentric) model explain the retrograde motions of the planets? Answer by means of construction on the diagram below, which shows the orbits of the earth and Mars around the sun, with the 'fixed' stars in the far distance (not to scale).




Referring to your diagram, explain briefly why Mars periodically appears to move 'backward'. *[3]*

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(c) Kepler found that the Copernican model could account for the observed motions of most of the 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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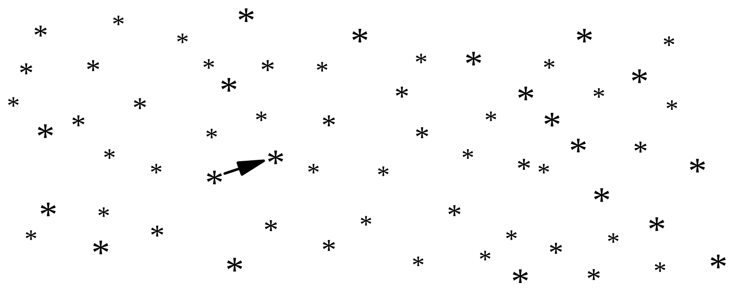
## OPTION F – ASTROPHYSICS

**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 $\theta$ 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 $\theta$ 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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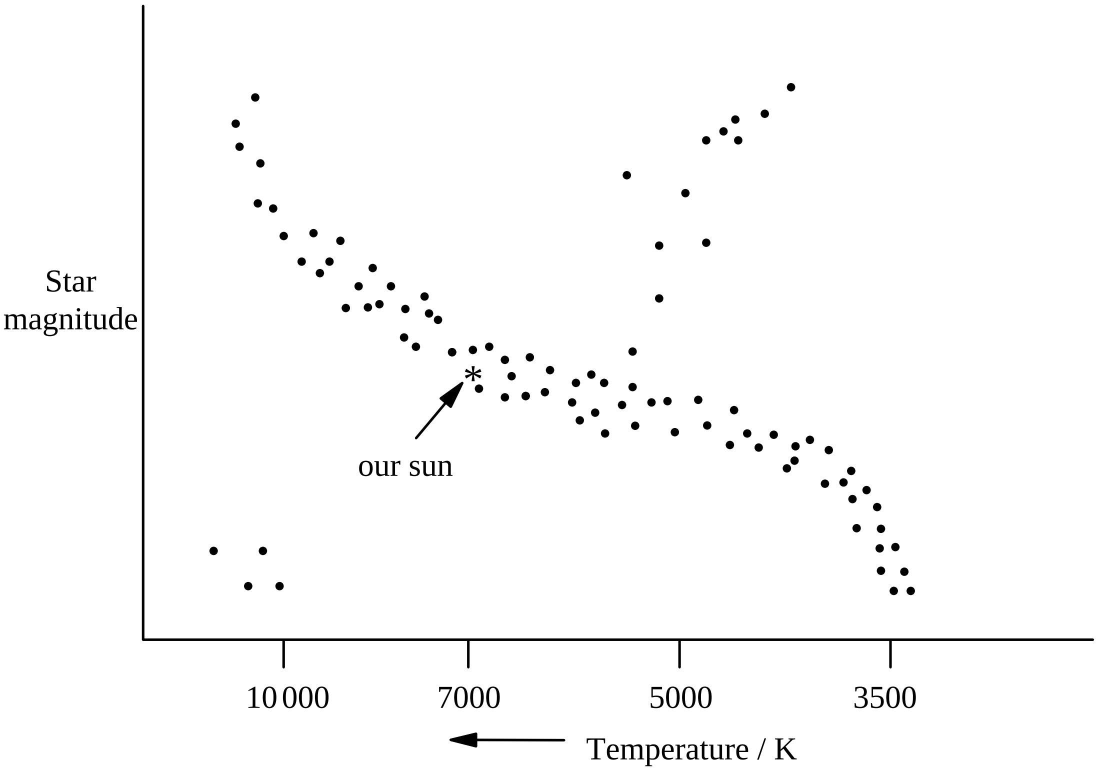
**F2. Hertzsprung-Russell diagram**

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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*(This question continues on the following page)*

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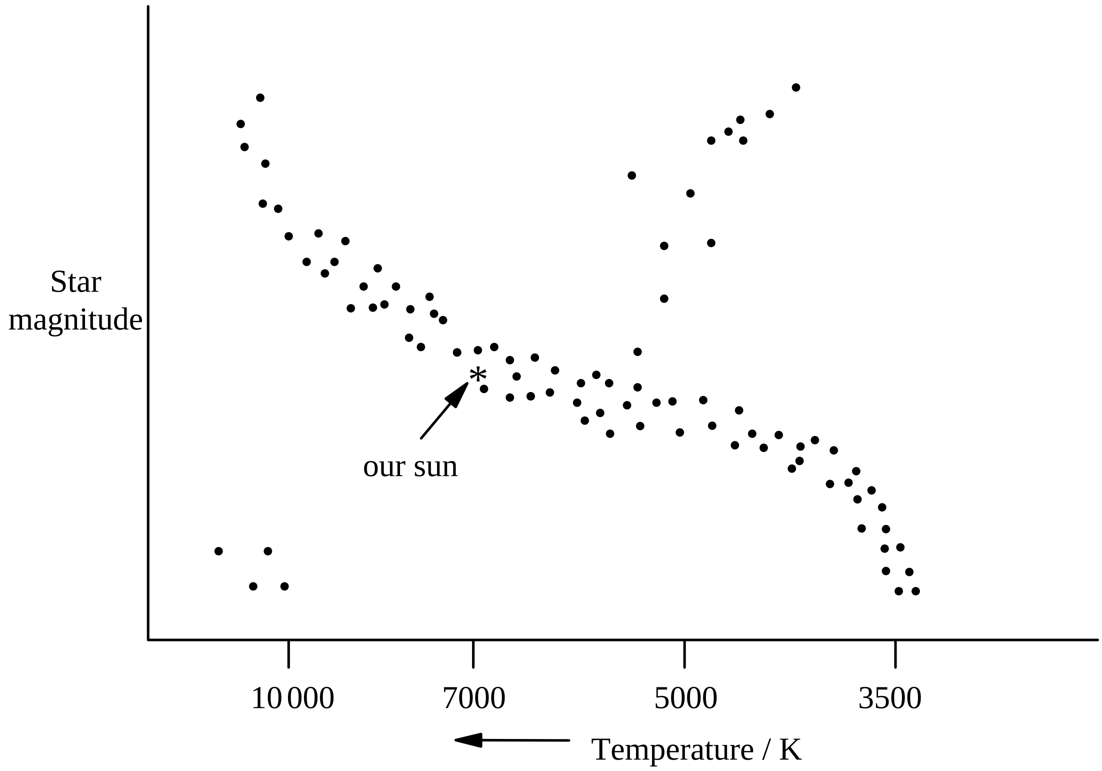
(ii) The position of our own sun on the H-R diagram is marked. Where on the diagram, relative to the sun, would the more massive star be located? Mark and label the region where it might occur. *[1]*



## 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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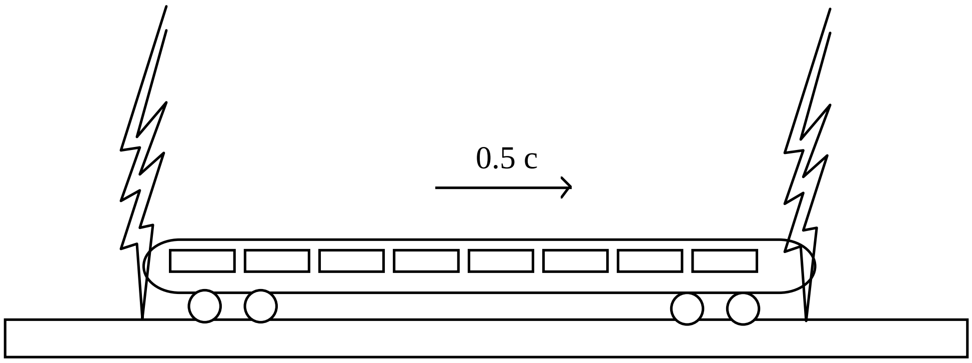
Einstein proposed a 'thought experiment' along the following lines. Imagine a train of proper length 100 m passing through a station at half the speed of light. There are two lightning strikes, one at the front and one at the rear of the train, leaving scorch marks on both the train and the station platform. 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 strikes 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]*

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

(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) 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]*

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(c) 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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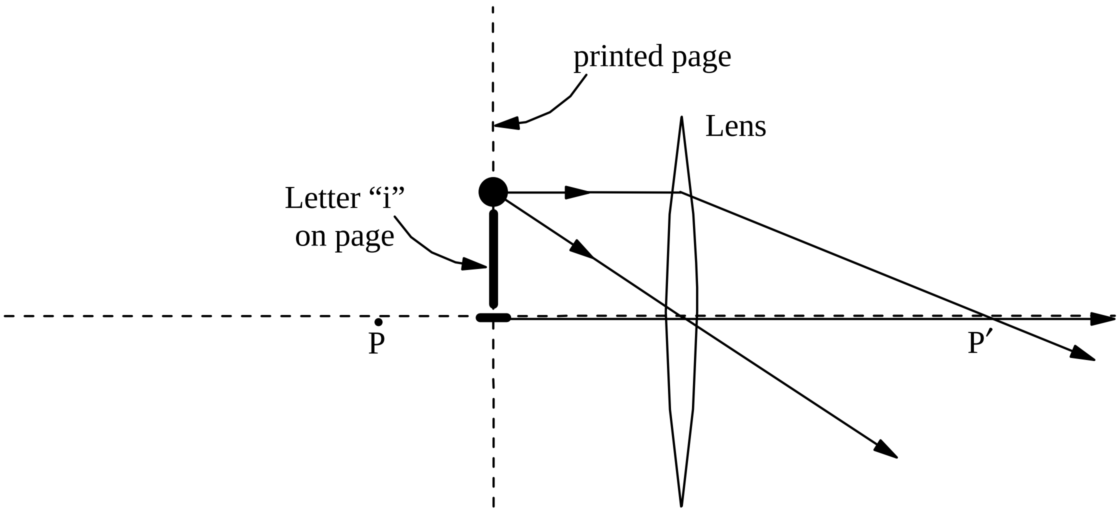
## OPTION H – OPTICS

### 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? . . . . . . .

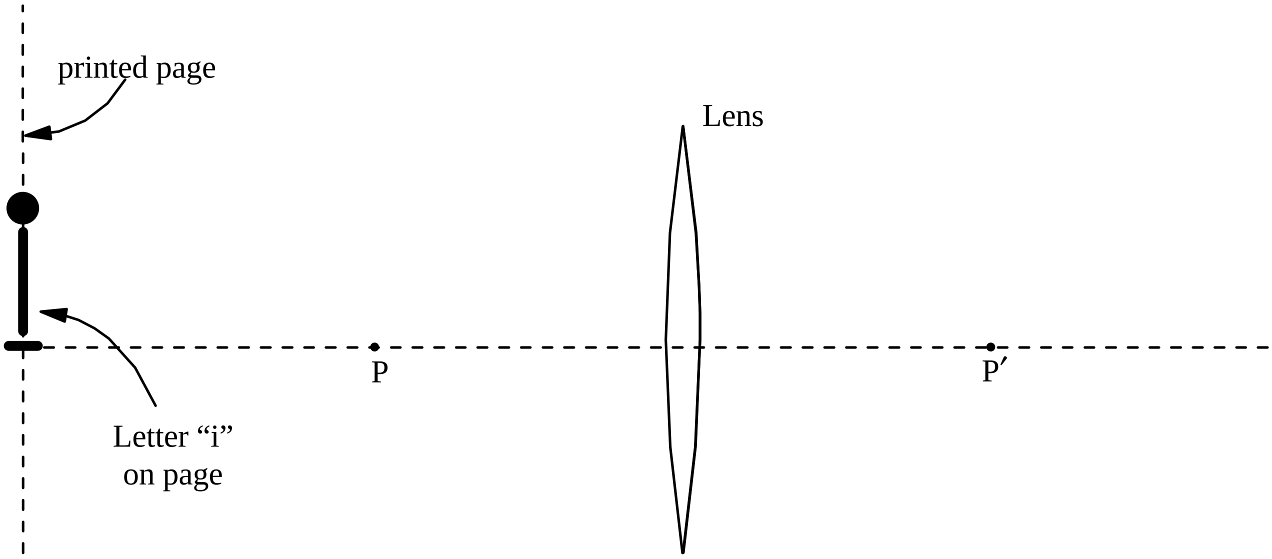
(iii) Instead of looking through the lens to see the image, could she 'capture' it by placing a screen or film at the image location? . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . *[1]*

*(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)**

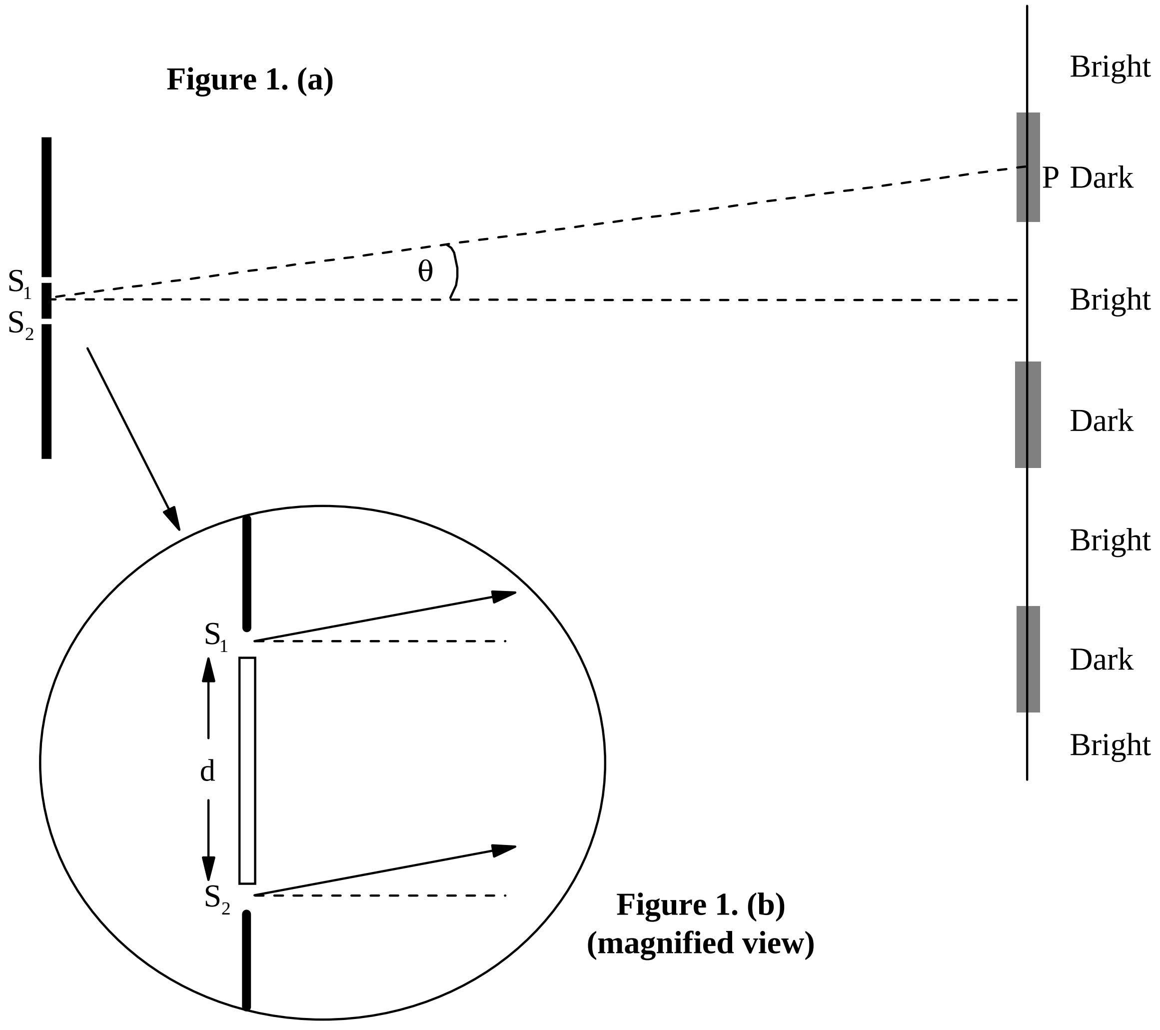


**Figure 1. (b)**
**(magnified view)**

Show that the angle θ at which the first **dark** fringe P occurs is given by the expression $\sin\theta = \lambda / 2d$, where $\lambda$ 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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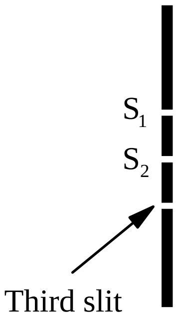
*(This question continues on the following page)*

*(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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