PHYSICS
HIGHER LEVEL
PAPER 3

Thursday 3 May 2007 (morning)

1 hour 15 minutes

Candidate session number

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INSTRUCTIONS TO CANDIDATES

- Write your session 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 candidate box on your cover sheet.

Option D — Biomedical Physics

D1. Dog A has a mass of 20 kg and dog B has a mass of 35 kg.

Determine the ratio

$$\frac{\text{rate of energy loss per unit mass for dog A}}{\text{rate of energy loss per unit mass for dog B}}.$$ *[4]*

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D2. This question is about hearing.

(a) State the range of frequencies audible to a normal adult human ear. *[1]*

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(b) Outline the role of the middle ear in the detection of sound. *[1]*

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(c) Structures within the cochlea have different lengths and stiffness. Outline how these structures enable different frequencies present in a sound wave to be distinguished. *[2]*

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(d) Explain how speech discrimination can be affected by changes in the functioning of the cochlea. *[3]*

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This question continues on the following page)

(Question D2 continued)

(e) A person with defective hearing can hear sounds with a minimum intensity of $6.0 \times 10^{-9}\,\text{W}\,\text{m}^{-2}$ at 3.0 kHz.

Determine the loss of hearing in dB of this person at this frequency. *[2]*

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D3. This question is about the absorption of X-radiation in body tissues.

(a) State **two** attenuation mechanisms by which X-rays are attenuated in body tissue. *[2]*

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(b) (i) Outline the basis of computed tomography (CT) imaging. *[3]*

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(ii) Describe how a standard X-ray photographic image differs from a computed tomography image. *[2]*

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D4. This question is about metabolic rate.

The energy in a slice of bread is sufficient to provide the gravitational potential energy for a person to climb a mountain.

Discuss why the person's energy requirement is greater than that provided by the bread. *[4]*

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D5. This question is about radioactive isotopes used in medicine.

Iodine-131 may be used in medical diagnosis to identify bleeding sites within the body.

(a) Outline in what way and why the effective half-life of the iodine is different from the physical half-life. *[3]*

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(b) The physical half-life of iodine-131 is 8 d and its biological half-life is 75 d.

(i) Calculate the effective half-life of the iodine-131. *[1]*

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(ii) Suggest why biological half-life should be much longer than the physical half-life. *[2]*

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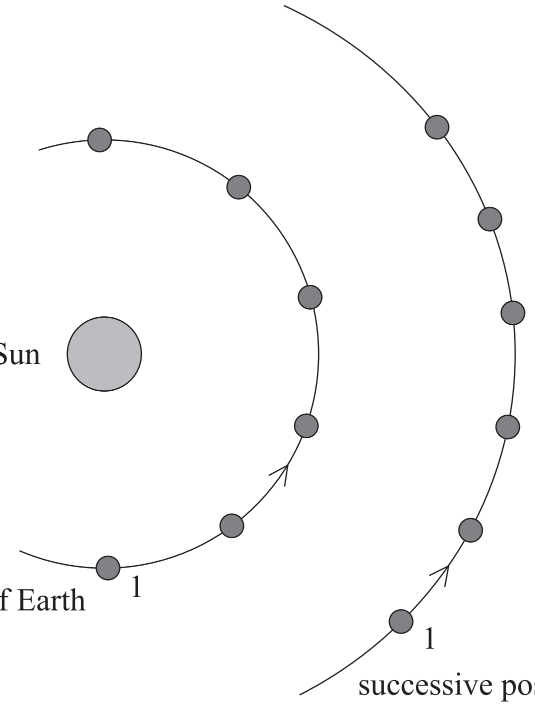
Option E — The History and Development of Physics

E1. This question is about planetary motion.

(a) The diagram below shows successive positions of the Earth and Mars in their orbits about the Sun. The positions are plotted at equal time intervals starting from the time when the Earth and Mars are in position 1.



(i) State what is meant by *retrograde motion*. *[1]*

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(ii) Use the diagram to explain retrograde motion. *[2]*

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(This question continues on the following page)

(Question E1 continued)

(b) Suggest why, from the Earth,

(i) only one side of the Moon is visible. *[3]*

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(ii) the Moon rises in a different position each day during a lunar month. *[2]*

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E2. This question is about Newton's law of gravitation.

Newton is said to have developed his law of gravitation after watching an apple fall from a tree.

(a) Explain why this law is said to be *universal*. *[1]*

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(b) Describe the contribution Newton's law of gravitation made to the acceptance of Kepler's laws of planetary motion. *[2]*

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E3. This question is about Thomson's experiment to measure the ratio of the charge to mass of an electron.

In his experiment to measure the electron charge-mass ratio, Thomson needed to know the speed of electrons as they passed through an electric field.

Outline how this speed was measured. *[4]*

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E4. This question is about models of the nuclear atom.

Thomson and Rutherford both suggested models of the atom.

(a) Compare the atomic models of Thomson and Rutherford. *[3]*

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(b) The existence of the neutron was suggested in the early part of the twentieth century. Suggest why the neutron was not detected until 1932. *[2]*

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E5. This question is about the Bohr theory of the hydrogen atom.

(a) State **one** success and **one** limitation of the Bohr model of the hydrogen atom. *[2]*

Success: . . . .

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Limitation: . . . .

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(b) Determine the ionization energy of atomic hydrogen. The Rydberg constant is $1.1 \times 10^{7}\,\text{m}^{-1}$. *[4]*

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(This question continues on the following page)

(Question E5 continued)

(c) Outline how the ideas of de Broglie enabled Schrödinger to formulate an alternative model of the hydrogen atom that allowed stable orbits to exist without contradicting electromagnetic theory. In your answer, you should distinguish carefully between the ideas of de Broglie and Schrödinger. *[4]*

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Option F — Astrophysics

F1. This question is about the brightness of stars.

(a) (i) Define the *luminosity of a star*. *[1]*

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(ii) State **one** factor that determines the luminosity of a star. *[1]*

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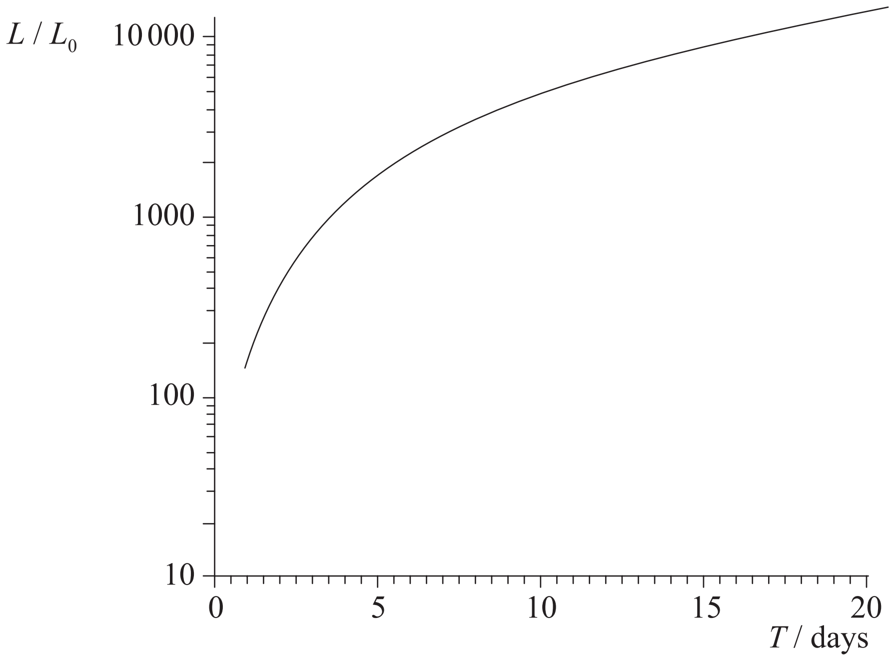
(This question continues on the following page)

(Question F1 continued)

(b) The graph below shows the variation with period T of the luminosity L of Cepheid variable stars, where the luminosity of the Sun is taken to be L_0.



(i) Outline why the luminosity of a Cepheid star varies periodically. *[2]*

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(ii) Cepheid variable star A has a period of 3.5 d; Cepheid variable star B has a period of 16.5 d. Star A is a distance of 1.6×10^{21} m from Earth and has an apparent brightness at the Earth $1.2\times10^{-14}\,\text{W m}^{-2}$. The apparent brightness of star B at the Earth is $5.3\times10^{-16}\,\text{W m}^{-2}$.

Determine the distance of star B from the Earth. *[4]*

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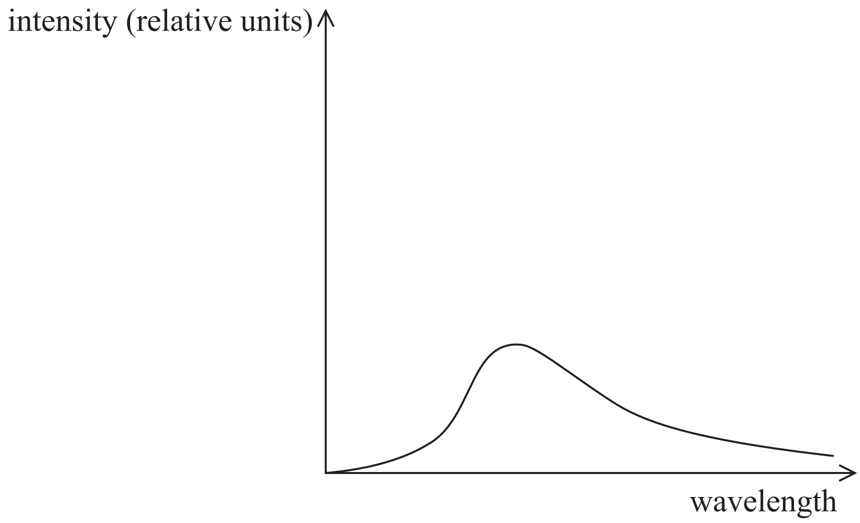
F2. This question is about cosmology.

(a) The diagram below shows the spectrum of the radiation emitted by a black body.



(i) On the diagram above, sketch the spectrum of radiation emitted by the black body at a higher temperature. *[2]*

(ii) State what is meant by *cosmological background radiation*. *[2]*

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(iii) Explain how knowledge of the spectrum of a black body and the existence of cosmological background radiation is consistent with the "Big Bang" model of the universe. *[3]*

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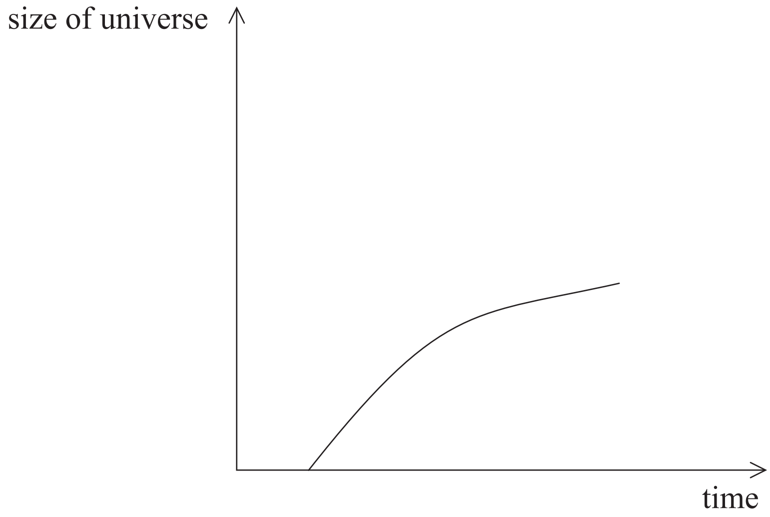
(Question F2 continued)

(b) The diagram below shows one suggestion for the variation with time of the size of the universe. This suggestion is referred to as the "flat" universe.



(i) On the diagram above, draw a line to represent an "open" universe (label this line O) and a line to represent a "closed" universe (label this line C). *[3]*

(ii) State and explain the condition, in terms of critical density of matter in the universe, for the universe to be closed. *[2]*

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F3. This question is about galaxies.

(a) Distinguish between a *galaxy* and a *galactic supercluster*. *[3]*

Galaxy:

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Galactic supercluster:

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(b) A galaxy is 190 Mpc from the Sun and is receding at a speed of $1.3 \times 10^{7}\,\text{m s}^{-1}$.

Use these data to determine a value for the age of the universe. *[3]*

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F4. This question is about stellar evolution.

(a) Describe the Chandrasekhar limit. *[1]*

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(b) A main sequence star has a mass of twenty solar masses.

Outline, with reference to the Chandrasekhar limit, the evolution of the star after leaving the main sequence. *[3]*

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Option G — Relativity

G1. This question is about time dilation.

(a) Define the following terms.

(i) *Proper length* *[1]*

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(ii) *Proper time* *[1]*

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(This question continues on the following page)

(Question G1 continued)

(b) A muon is created in the Earth's atmosphere by a cosmic ray striking an oxygen atom. The speed of the muon as measured by an observer on Earth is $0.99c$ where c is the speed of light. The muon decays after a time of 3.1×10^{-6} s as measured in its reference frame.

Calculate,

(i) the distance travelled by the muon as measured in its reference frame. *[2]*

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(ii) for an observer on Earth, the lifetime of the muon and the distance it travels before it decays. *[3]*

Lifetime: . . . .

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Distance: . . . .

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(c) Use your answers to (b) to explain time dilation. *[2]*

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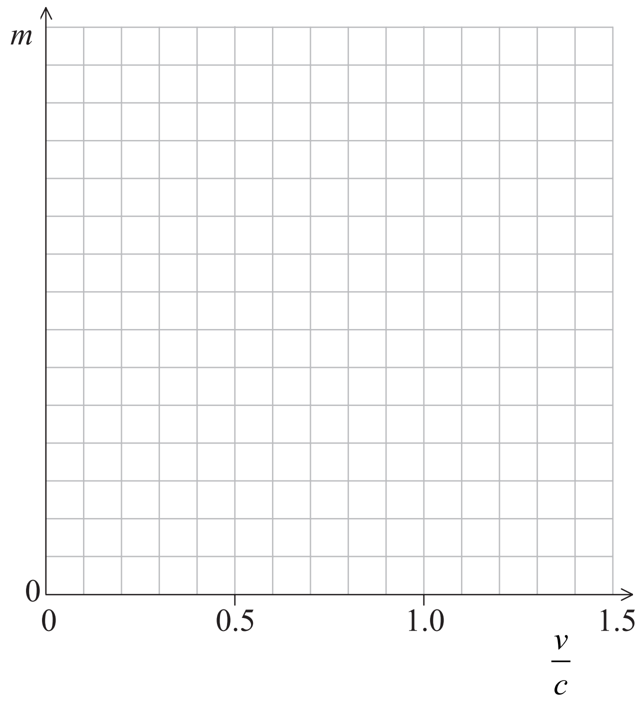
G2. This question is about relativistic mass increase.

(a) Electrons are accelerated from rest through a potential difference. On the axes below, draw a sketch graph to show how the mass m of an electron varies with its speed, $\frac{v}{c}$. (Note: no numerical values are required.) *[3]*



(b) An electron is accelerated through a potential difference of 2.0 MV. The rest mass of the electron is 0.50 MeV c^{-2}.

Determine for the accelerated electron

(i) the final mass in MeV c^{-2}. *[1]*

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(ii) the final speed in terms of c after acceleration. *[3]*

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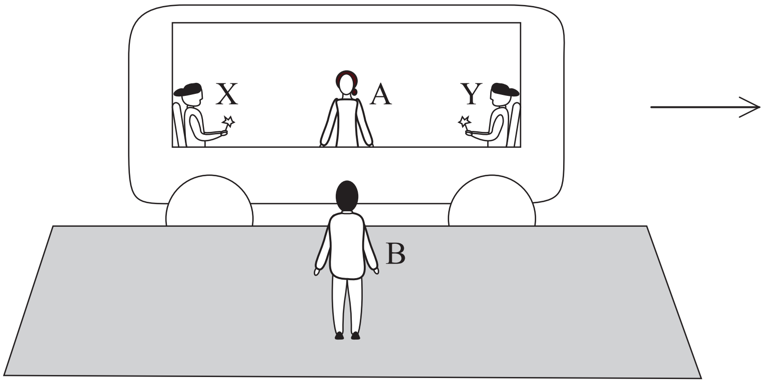
G3. This question is about simultaneity.

Two people, X and Y, are facing each other at opposite ends of a railway carriage. Person A is also in the carriage, midway between them. The carriage is moving in a straight-line with uniform speed relative to person B who is standing at the side of the railway track.

When person A is opposite person B, the two people X and Y each switch on a light. Person A sees the lights at the same time, *i.e.* simultaneously.



Discuss whether person B will describe the switching on of the lights as occurring simultaneously. *[4]*

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G4. This question is about black holes.

(a) (i) By a reference to space-time, describe the nature of a black hole. *[2]*

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(ii) By reference to your answer to (a), define the Schwarzchild radius. *[1]*

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(iii) A star has a mass of 4.0×10^{31} kg. It evolves into a black hole.

Calculate the Schwarzchild radius of the black hole, stating any assumption that you make. *[2]*

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(This question continues on the following page)

(Question G4 continued)

(b) A spacecraft approaches the black hole in (a)(iii). If it were to continue to travel in a straight-line it would pass within 10^6 m of the black hole.

(i) Suggest what effect the black hole would have on the motion of the spacecraft. *[1]*

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(ii) Explain gravitational attraction in terms of the warping of space-time by matter. *[4]*

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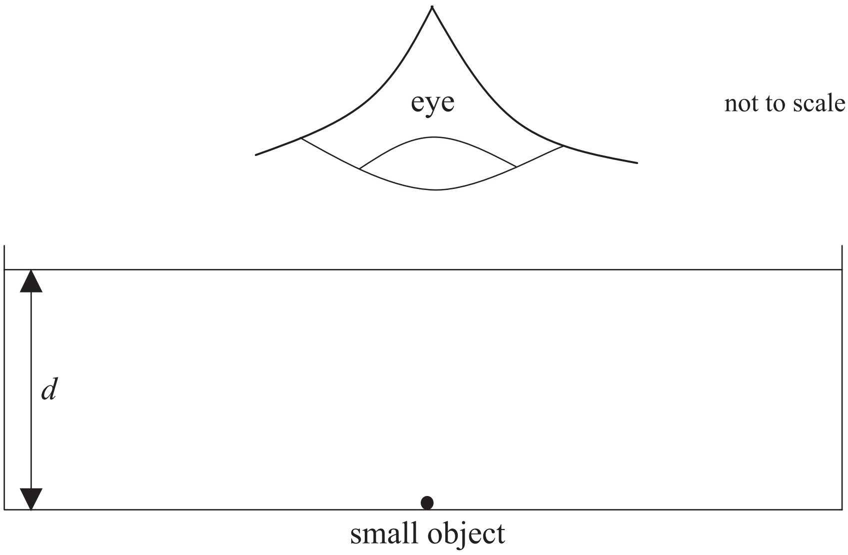
Option H — Optics

H1. This question is about refractive index.

(a) A small object rests at the bottom of a swimming pool of depth *d*. Viewed from directly above, the object appears to be 5.0 m below the surface of the water.



(i) On the diagram above, draw rays to locate the image of the object as seen from above. *[2]*

(ii) The refractive index of water = 1.3.

Determine the depth *d* of the swimming pool. *[2]*

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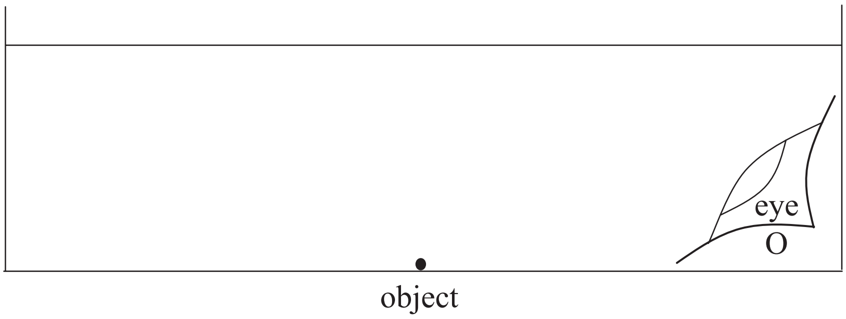
(This question continues on the following page)

(Question H1 continued)

(b) A diver views the surface of the water from point O as shown in the diagram below.



not to scale

(i) On the diagram above, draw **two** rays to locate the image of the object as seen by the diver at O. *[3]*

(ii) Explain why the surface of the water needs to be undisturbed for the image to be seen. *[1]*

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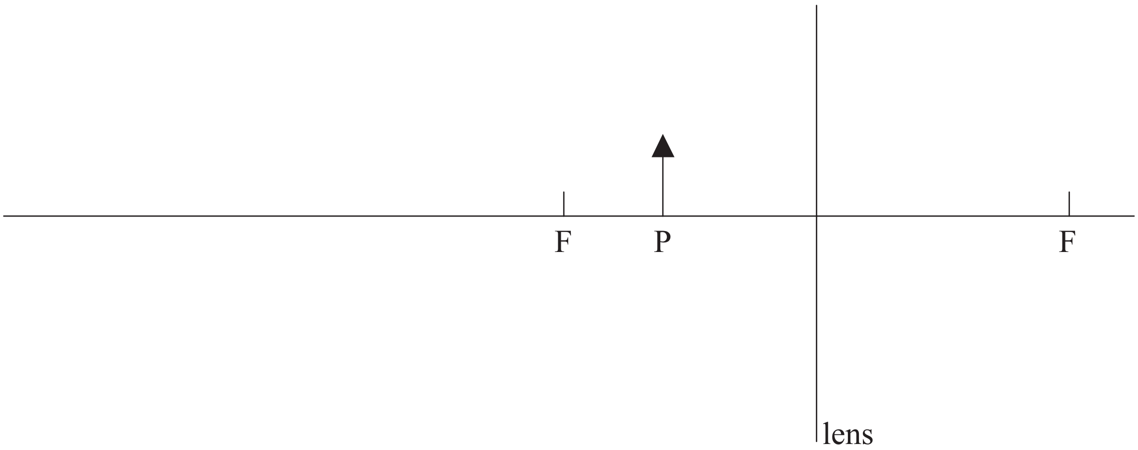
H2. This question is about image formation by a converging lens.

An object P is placed close to a converging lens as shown in the diagram below. The principal foci F of the lens are marked.



(a) On the diagram above, draw rays to locate the position of the image formed by the lens. Label this image with the letter I. *[3]*

(b) The near point of an observer's eye is 25.0 cm from the eye. The lens in the diagram is positioned 4.0 cm from the lens in the observer's eye so as to form an image of the object P at the near point. The focal length of the lens is 8.0 cm.

(i) Define the term *near point*. *[1]*

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(ii) Determine the distance from the object to the lens. *[3]*

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(This question continues on the following page)

(Question H2 continued)

(c) (i) Lenses are subject to chromatic aberration and spherical aberration.

Describe and explain *chromatic aberration* and *spherical aberration*. *[4]*

Chromatic aberration: . . . .

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Spherical aberration: . . . .

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(ii) Suggest how the effects of spherical aberration can be reduced. *[1]*

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H3. This question is about diffraction and resolution.

Blue light of wavelength 450 nm from a star passes through a telescope with a circular aperture of 0.25 m and forms an image on a photographic plate 0.75 m from the focussing lens.

(a) (i) In the space provided below, draw a labelled sketch to show the diffraction fringe pattern produced on the photographic plate. *[2]*

(ii) Calculate the diameter of the central maximum on the photographic plate. *[2]*

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(This question continues on the following page)

(Question H3 continued)

(b) The telescope in (a) is now pointed at two stars.

The maximum separation of the stars is d and they are both 1.5×10^{17} m from the telescope.

(i) Determine the separation d of the stars such that the images of the stars are just resolved in light of wavelength 450 nm. *[3]*

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(ii) Over a period of time the separation of the stars varies from $\frac{d}{2}$ to $2d$.

Describe and explain the changes to the image produced by the telescope during this time. You should include diagrams to illustrate your answer. *[3]*

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