IB DIPLOMA PROGRAMME
PROGRAMME DU DIPLÔME DU BI
PROGRAMA DEL DIPLOMA DEL BI

M04/431/H(3)+

PHYSICS
HIGHER LEVEL
PAPER 3

Candidate number

Wednesday 5 May 2004 (morning)

1 hour 15 minutes

INSTRUCTIONS TO CANDIDATES

- Write your candidate number in the box 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.

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Option D — Biomedical Physics

D1. This question is about scaling.

The amount of water that can be stored in a body is proportional to the volume of the body. The rate of water loss through evaporation is proportional to the surface area of the body.

(a) State how the following quantities scale with the linear dimension L of the body.

(i) Mass of water stored: . . . . . *[1]*

(ii) Rate of water loss: . . . . . *[1]*

The time taken between drinks by an adult in order to maintain normal water content is T.

(b) (i) Suggest why T is proportional to L. *[2]*

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(ii) An ordinary adult person can go without water for three days. Estimate how long a child can go without water. *[3]*

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D2. This question is about medical imaging.

(a) State and explain which imaging technique is normally used

(i) to detect a broken bone. *[2]*

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(ii) to examine the growth of a fetus. *[2]*

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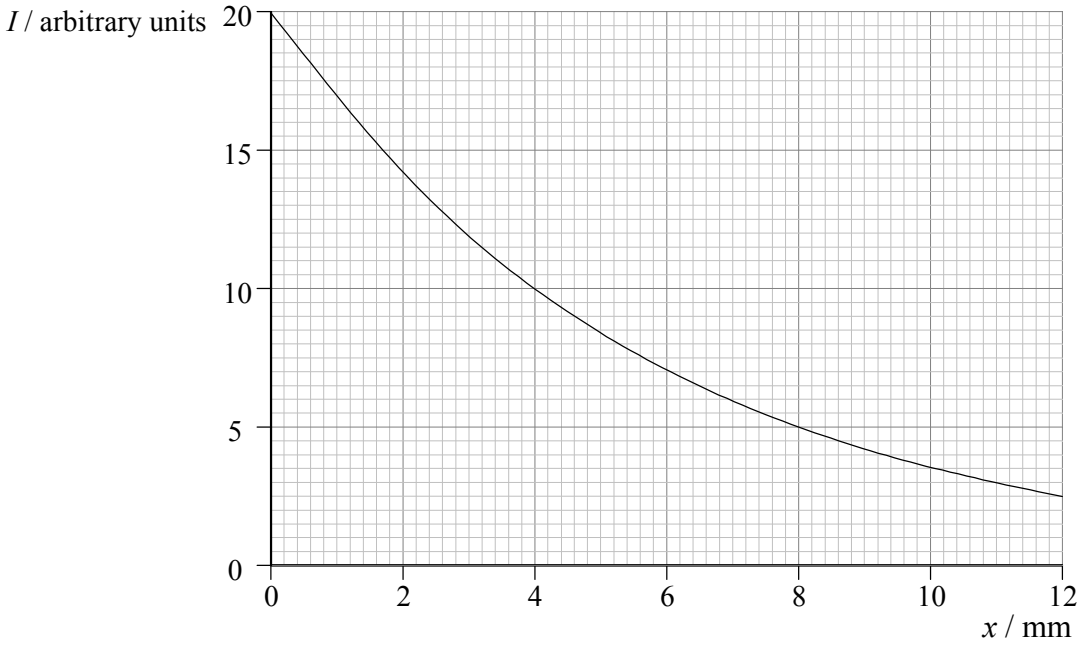
The graph below shows the variation of the intensity I of a parallel beam of X-rays after it has been transmitted through a thickness x of lead.



(b) (i) Define *half-value thickness*, $x_{\frac{1}{2}}$. *[2]*

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(ii) Use the graph to estimate $x_{\frac{1}{2}}$ for this beam in lead. *[2]*

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(This question continues on the following page)

(Question D2 continued)

(iii) Determine the thickness of lead required to reduce the intensity transmitted to 20 % of its initial value. *[2]*

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(iv) A second metal has a half-value thickness $x_{\frac{1}{2}}$ for this radiation of 8 mm. Calculate what thickness of this metal is required to reduce the intensity of the transmitted beam by 80 %. *[3]*

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D3. This question is about energy in the human body.

(a) State what is meant by basal metabolic rate. *[2]*

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(b) When a person is exercising, energy must be lost into the surroundings in order that the body does not overheat. Describe **two** mechanisms by which energy is lost from the body. *[4]*

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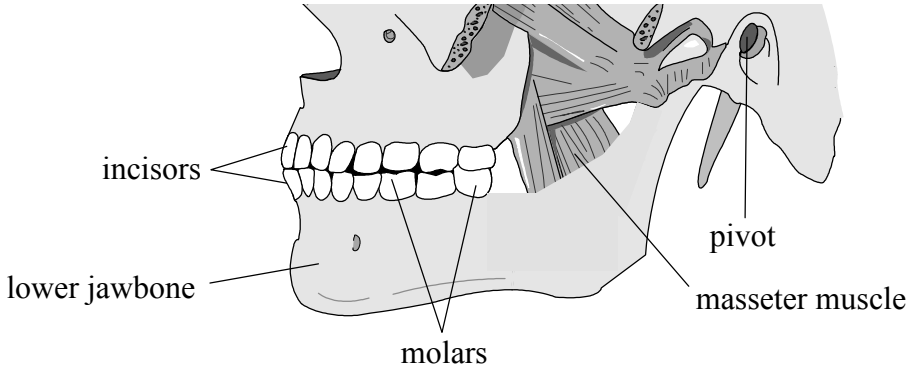
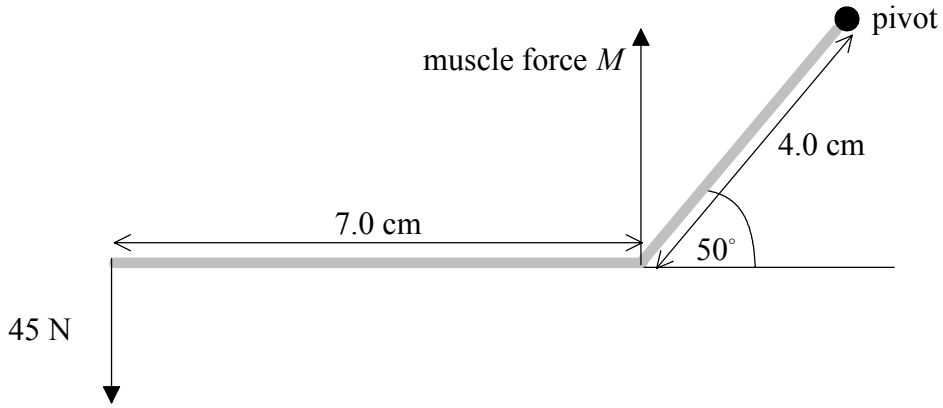
D4. This question is about forces in the human body.

The diagram below shows the position of a person's jawbones.



The lower jawbone may be represented by the model below.



The jawbone has negligible mass. It consists of two straight parts of length 7.0 cm and 4.0 cm making an angle of 50° to each other. During one particular bite, a force of 45 N is applied by the teeth at the front of the jawbone.

(a) Calculate the magnitude M of the force applied by the masseter muscle. *[2]*

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(b) Suggest why teeth used for crushing hard food are found at the back, rather than the front of the jaw. *[2]*

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Option E — The History and Development of Physics

E1. This question is about the motion of the planets.

(a) Describe what is meant by retrograde motion. *[2]*

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(b) Outline how the heliocentric model of the solar system accounts for the retrograde motion of Mars. *[2]*

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E2. This question is about electric charge.

A glass rod rubbed with silk becomes positively charged and a piece of amber rubbed with fur becomes negatively charged.

Describe how the electrification of the glass and of the piece of amber are explained

(a) by du Fay's theory of electric charge.

Glass: . . . . . *[1]*

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Amber: . . . . . *[1]*

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(b) by the modern concept of electric charge.

Glass: . . . . . *[1]*

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Amber: . . . . . *[1]*

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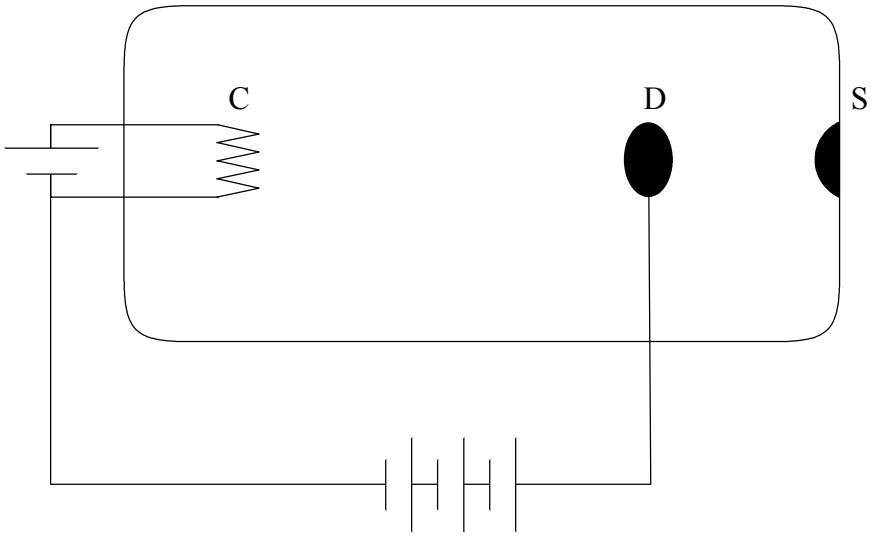
E3. This question is about cathode rays.

Investigations of cathode rays may be carried out using the apparatus shown below.



The cathode rays were formed at C and were accelerated toward the solid disc at D. A clear shadow of the disc is formed at S. A bar magnet held near the tube between C and D caused the shadow to move.

(a) Explain why this movement of the shadow implies

(i) that the cathode rays are not electromagnetic waves. *[2]*

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(ii) that cathode rays are particles. *[2]*

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(This question continues on the following page)

(Question E3 continued)

Hertz attempted to detect the deflection of cathode rays in the electric field between parallel oppositely charged plates in air.

(b) Suggest

(i) why his experiment was not successful. *[2]*

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(ii) how Thompson modified the experiment to give the desired result. *[1]*

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Thompson measured the ratio of charge to mass q/m of cathode rays. A beam of cathode rays passes "without deflection" through the region of uniform magnetic field normal to a uniform electric field. The magnetic field and the electric field have strength 0.76 mT and 4.6×10^4 Vm^{-1} respectively.

(c) (i) Calculate the speed of the cathode rays. *[2]*

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(ii) The radius of the circular path of the cathode rays when in the magnetic field only is 0.45 m. Deduce the ratio of q/m for the cathode rays. *[3]*

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E4. This question is about atomic models.

The Bohr model was developed in order to explain the atomic spectrum of hydrogen.

(a) Explain how the Bohr model was used to explain the spectrum of atomic hydrogen. *[4]*

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(b) State **one** limitation of the Bohr model. *[1]*

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A later model of the atom was developed by Schrödinger.

(c) (i) State **two** differences between the model of Bohr and the model of Schrödinger. *[2]*

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(ii) Explain how the Schrödinger theory is consistent with the Heisenberg uncertainty principle. *[3]*

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Option F — Astrophysics

F1. This question is about Cepheid variables.

(a) Define

(i) *luminosity*. *[1]*

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(ii) *apparent brightness*. *[1]*

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(b) State the mechanism for the variation in the luminosity of the Cepheid variable. *[1]*

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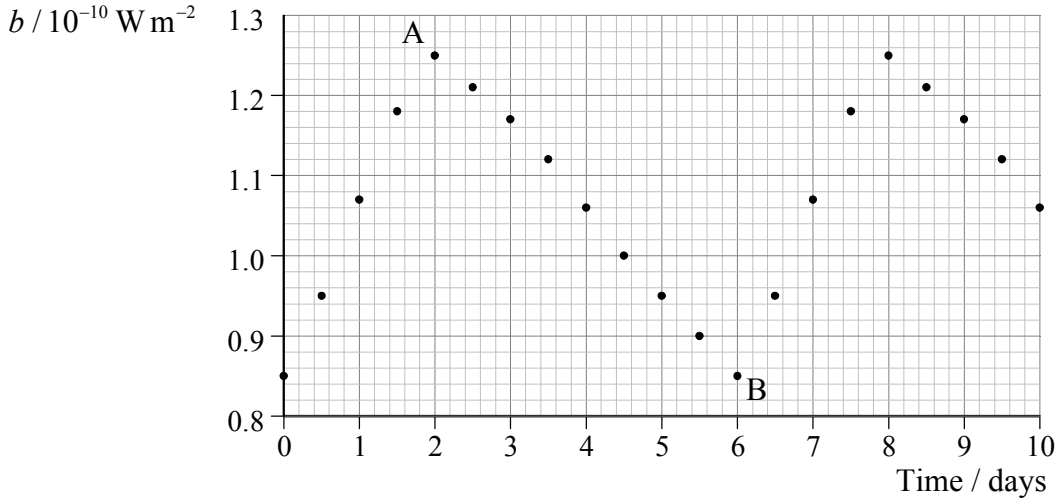
The variation with time t, of the apparent brightness b, of a Cepheid variable is shown below.



Two points in the cycle of the star have been marked A and B.

(c) (i) Assuming that the surface temperature of the star stays constant, deduce whether the star has a larger radius after two days or after six days. *[2]*

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(This question continues on the following page)

(Question F1 continued)

(ii) Explain the importance of Cepheid variables for estimating distances to galaxies. *[3]*

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(d) (i) The maximum luminosity of this Cepheid variable is 7.2×10^{29} W. Use data from the graph to determine the distance of the Cepheid variable. *[3]*

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(ii) Cepheids are sometimes referred to as "standard candles". Explain what is meant by this. *[2]*

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F2. This question is about the Big Bang model.

(a) Describe what is meant by *cosmic background radiation*. *[2]*

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(b) Explain how cosmic background radiation is evidence in support of the Big Bang model of the universe. *[2]*

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(c) State **one** other piece of evidence in support of the Big Bang model. *[1]*

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(d) A student makes the statement that *"as a result of the Big Bang, the universe is expanding into a vacuum"*. Discuss whether the student's statement is correct. *[2]*

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F3. This question is about galaxies.

(a) Draw a sketch showing the basic structure of the Milky Way galaxy. Mark the approximate position of the solar system. *[3]*

(b) A particular spectral line of light from a laboratory source has a wavelength of 658 nm. The wavelength of this line of light from a distant galaxy is 670 nm. Calculate the recessional speed of the galaxy. *[2]*

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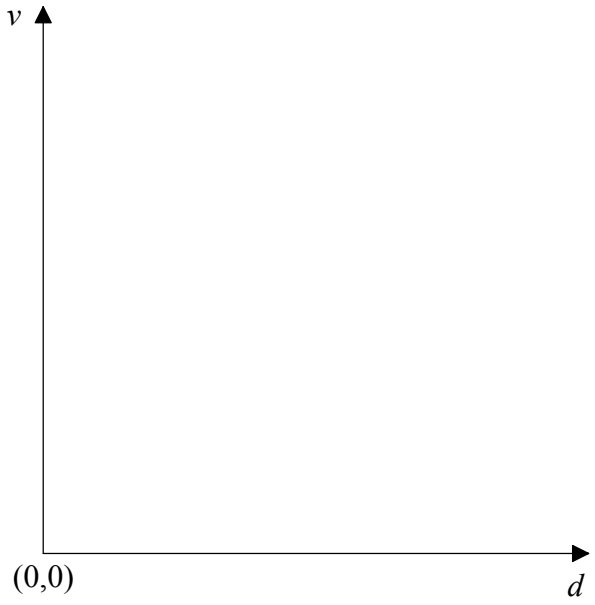
(This question continues on the following page)

(Question F3 continued)

(c) (i) Draw a sketch graph to show how the recessional speed of galaxies varies with distance from Earth. *(This is a sketch graph; you do not need to put any values on the axes.)* *[2]*



(ii) Deduce how $\frac{1}{H_0}$ may be used to estimate the age of the universe. *[2]*

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(iii) Outline how Hubble's constant, H_0 is determined from your graph. *[1]*

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Option G — Relativity

G1. This question is about effects of special relativity.

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

Postulate 1: . . . . . .

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Postulate 2: . . . . . .

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A super-fast spacecraft is moving at a speed of $0.80\,c$ with respect to observers on Earth. The spacecraft leaves Earth in May 2004 on its way to a distant solar system.

(b) (i) According to the observers in the spacecraft 6.0 years have elapsed since leaving Earth. Calculate the time elapsed according to an observer on Earth. *[3]*

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(ii) Explain which time interval is the proper time interval. *[1]*

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(iii) Explain whether either measured time interval can be considered to be "correct". *[2]*

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(iv) Calculate the distance of the spacecraft from Earth according to an observer on Earth. *[2]*

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(This question continues on the following page)

(Question G1 continued)

(v) The observers in the spacecraft send a radio message to Earth to say that they have been travelling for 6.0 years. Determine how long it will take the message to get to Earth according to the **spacecraft observers**. *[3]*

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G2. This question is about relativistic mechanics.

(a) Define *rest mass*. *[1]*

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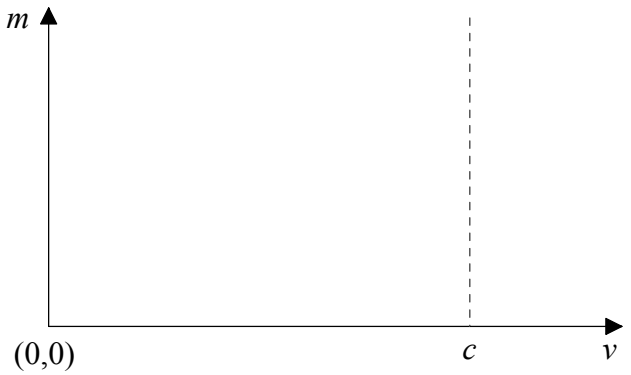
(b) On the axes below draw a sketch graph to show the variation of mass m with speed v for a particle called a muon whose rest mass is $106\,\text{MeV}\,c^{-2}$. *(This is a sketch graph; you do not need to put any values on the axes.)* *[2]*

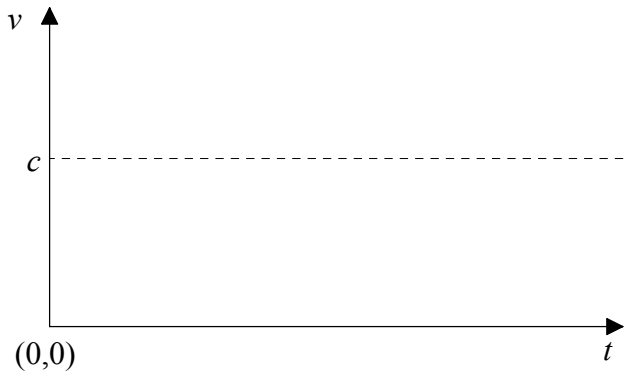


(c) A constant force acts on the muon. On the axes below draw a sketch graph to show the variation with time t, of the speed v of the muon according to

(i) Newtonian physics (label this graph N).

(ii) relativistic physics (label this graph R). *[2]*

(These are sketch graphs; you do not need to put any values on the axes.)



(iii) Explain why the two graphs are different as the speed approaches the speed of light. *[2]*

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G3. This question is about General Relativity.

(a) State the principle of equivalence. *[2]*

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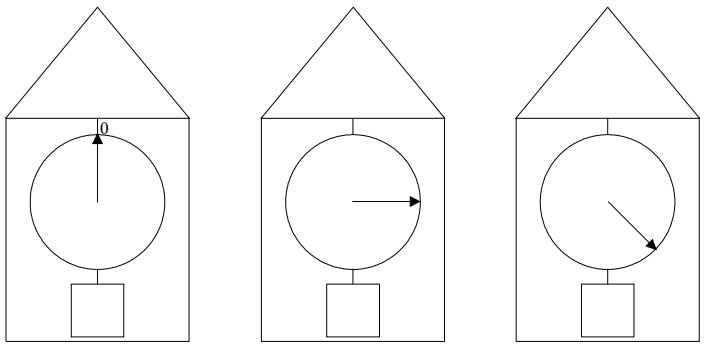
A spacecraft is initially at rest on the surface of the Earth. It then accelerates away from Earth into deep space where it then moves with constant velocity. There is a spring balance supporting a mass from the ceiling.



A B C

The diagrams show the readings on the spring balance at these different stages of the motion.

(b) Identify and explain, in each case, the motion of the spacecraft that could give rise to the reading shown

(i) at rest on the Earth's surface. *[2]*

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(ii) moving away from Earth with acceleration. *[2]*

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(iii) moving at constant velocity in deep space. *[2]*

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(This question continues on the following page)

(Question G3 continued)

The spacecraft now accelerates in deep space with an acceleration equal to the acceleration of free fall at the Earth's surface.

(c) State and explain which of the readings A, B or C would now be observed on the spring balance. *[2]*

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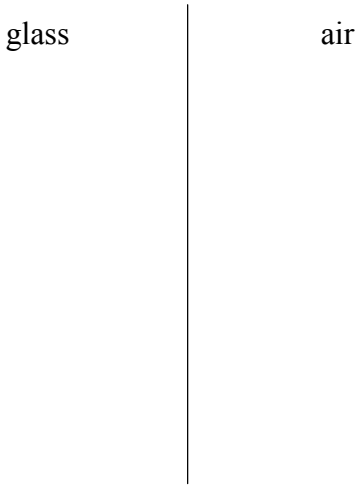
Option H — Optics

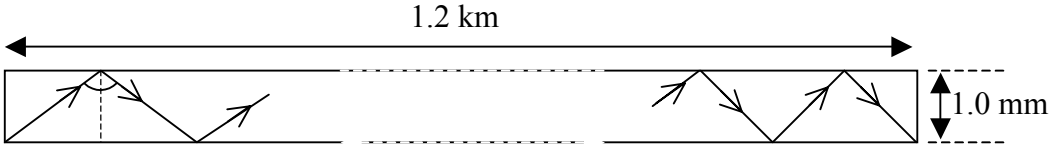
H1. This question is about refractive index and critical angle.

The diagram below shows the boundary between glass and air.



(a) On the diagram, draw a ray of light to illustrate what is meant by critical angle. Mark the critical angle with the letter "c". *[3]*

A straight optic fibre has length 1.2 km and diameter 1.0 mm. Light is reflected along the fibre as shown below.



At each reflection, the angle of incidence is equal in value to the critical angle. The refractive index of the glass of the fibre is 1.5.

(b) Deduce that the length of the light path along the optic fibre is about 1.8 km. *[4]*

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(This question continues on the following page)

(Question H1 continued)

The speed of light in the fibre is $2.0 \times 10^8 \, \mathrm{m\,s^{-1}}$.

(c) Calculate the time for a pulse of light to travel the length of the fibre when its path is

(i) along the axis of the fibre. *[1]*

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(ii) as calculated in (b). *[1]*

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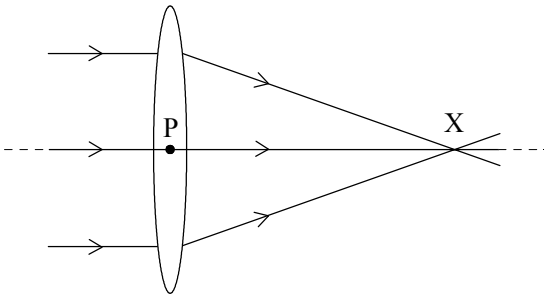
H2. This question is about lenses.

A parallel beam of light is incident on a convex lens of focal length 18 cm. The light is focused at point X as shown below.



(a) State the value of the distance PX. *[1]*

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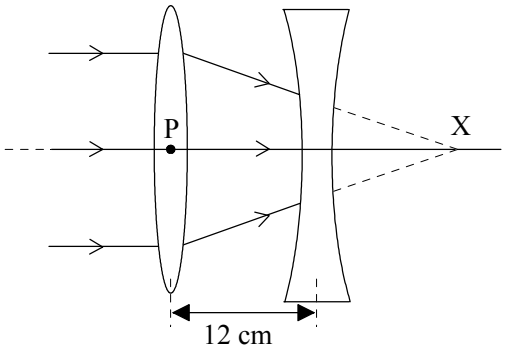
A diverging lens of focal length 24 cm is now placed 12 cm from the convex lens as shown below.



(b) (i) Explain why point X acts as a virtual object for the diverging lens. *[1]*

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(ii) Calculate the position of the image as produced by the diverging lens. *[3]*

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(This question continues on the following page)

(Question H2 continued)

(c) A lens combination, such as a diverging and a convex lens, is referred to as a telephoto lens. Suggest why a telephoto lens is considered to have a longer focal length than that of a single convex lens. *[2]*

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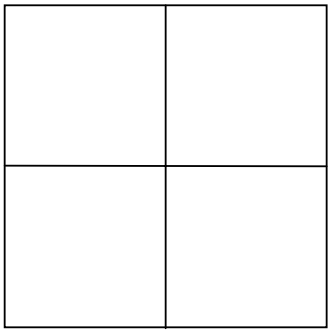
H3. This question is about spherical aberration.

The diagram below shows the image of a square grid as produced by a lens that does not cause spherical aberration.



(a) In the space below, draw a possible shape of this image, as produced by a lens that causes spherical aberration. *[2]*

(b) Describe **one** way in which spherical aberration can be reduced. *[2]*

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H4. This question is about optical resolution.

(a) Light from a point source is brought to a focus by a convex lens. The lens does not cause spherical or chromatic aberration.

(i) State why the image of the point source will not be a point image. *[1]*

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(ii) Describe the appearance of the image. *[2]*

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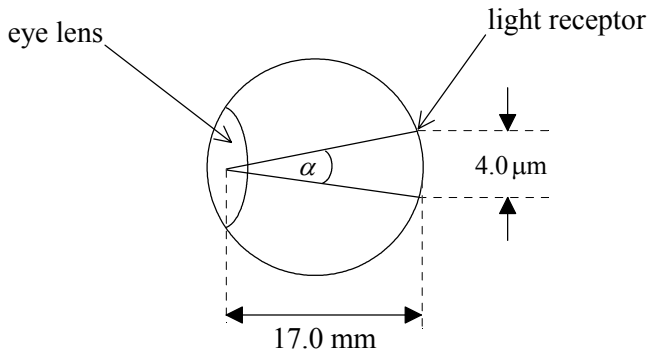
Two light receptors at the back of the eye are $4.0\,\mu m$ apart. The distance of the receptors from the convex lens at the front of the eye is 17.0 mm, as shown below.



Light of wavelength 550 nm from two point objects enters the eye. The centres of the images of the two objects are focused on the light receptors.

(b) (i) Calculate the angle α in radians subtended by the two receptors at the centre of the eye lens. *[2]*

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(This question continues on the following page)

(Question H4 continued)

(ii) Use the Rayleigh criterion to calculate the diameter of the pupil of the eye so that the two images are just resolved. *[2]*

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H5. This question is about oil films.

Explain briefly the formation of coloured images when white light is reflected at a film of oil on water. *[3]*

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