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

M04/431/S(3)+

PHYSICS
STANDARD LEVEL
PAPER 3

Candidate number

Wednesday 5 May 2004 (morning)

1 hour

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.

Option A — Mechanics Extension

A1. This question is about gravitation and orbital motion.

(a) Define *gravitational field strength* at a point in a gravitational field. *[2]*

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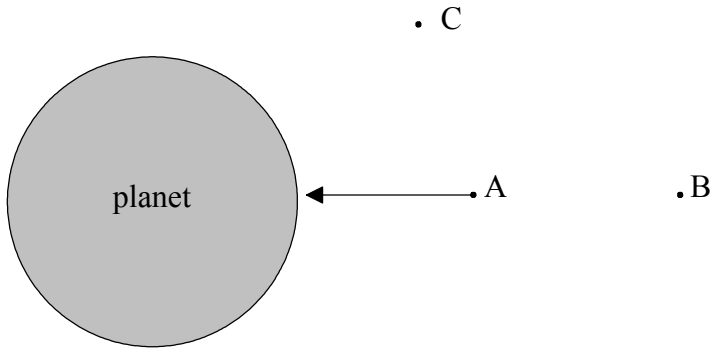
The diagram below shows three points above a planet. The arrow represents the gravitational field strength at point A.

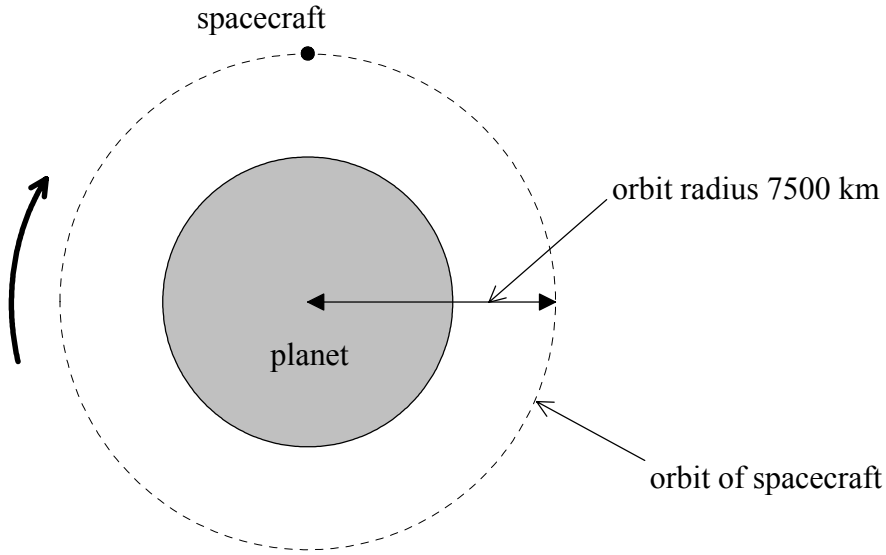


(b) Draw arrows to represent the gravitational field strength at point B and point C. *[2]*

(This question continues on the following page)

(Question A1 continued)

A spacecraft is in a circular orbit around the planet as shown in the diagram below. The radius of the orbit is 7500 km.



(c) For the spacecraft in the position shown, draw and label arrows representing

(i) the velocity (label this arrow V). *[1]*

(ii) the acceleration (label this arrow A). *[1]*

The speed of the spacecraft is $6.5\,\mathrm{km\,s^{-1}}$.

(d) Deduce the value of the magnitude of the gravitational field strength at a point in the spacecraft's orbit. *[3]*

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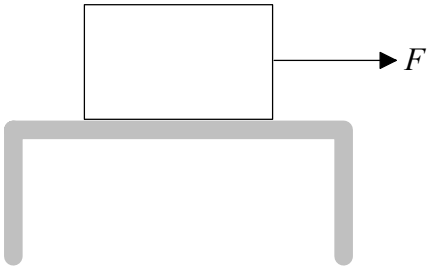
A2. This question is about frictional forces.

A block of mass 5.0 kg rests on a rough horizontal table as shown in the diagram below. A force F is applied to the block. The coefficient of static friction between the block and the table is 0.60 and the coefficient of sliding friction is 0.50.



(a) Explain why the block will not move unless F is greater than 30 N. *[3]*

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(b) Calculate the acceleration of the block when the pulling force F is equal to 70 N. *[3]*

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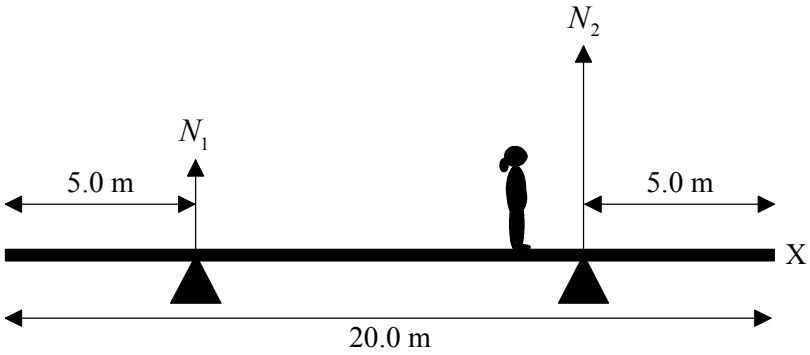
A3. This question is about rotational equilibrium.

The diagram shows a beam of length 20.0 m and mass 40.0 kg resting on two supports placed at 5.0 m from each end.



A girl of mass 50.0 kg stands on the beam between the supports. The reaction forces at the supports are shown.

(a) State the value of $N_1 + N_2$. *[1]*

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(b) The girl now moves towards end X of the beam. Determine the distance of the girl from end X when the beam is about to tip. *[4]*

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Option B — Quantum Physics and Nuclear Physics

B1. This question is about the photoelectric effect.

(a) State **one** aspect of the photoelectric effect that **cannot** be explained by the wave model of light. Describe how the photon model provides an explanation for this aspect. *[2]*

Aspect: . . . . . .

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Explanation: . . . . . .

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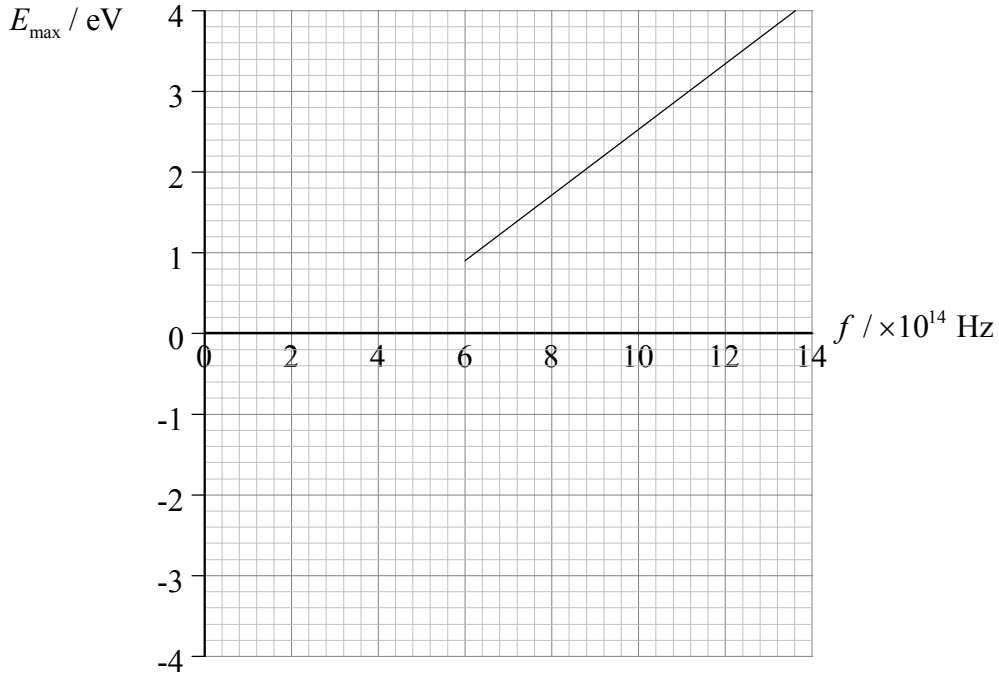
(This question continues on the following page)

(Question B1 continued)

Light is incident on a metal surface in a vacuum. The graph below shows the variation of the maximum kinetic energy E_{max} of the electrons emitted from the surface with the frequency f of the incident light.



(b) Use data from the graph to determine

(i) the threshold frequency. *[2]*

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(ii) a value of the Planck constant. *[2]*

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(iii) the work function of the surface. *[2]*

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(This question continues on the following page)

(Question B1 continued)

The threshold frequency of a different surface is 8.0×10^{14} Hz.

(c) On the axes opposite, draw a line to show the variation with frequency f of the maximum kinetic energy E_{max} of the electrons emitted. *[2]*

B2. This question is about particle physics.

(a) Possible particle reactions are given below. They **cannot** take place because they violate one or more conservation laws. For each reaction identify **one** conservation law that is violated.

(i) $\mu^- \rightarrow e^- + \gamma$ *[1]*

Conservation law: . . . . . .

(ii) $p + n \rightarrow p + \pi^0$ *[1]*

Conservation law: . . . . . .

(iii) $p \rightarrow \pi^+ + \pi^-$ *[1]*

Conservation law: . . . . . .

(b) State the name of the exchange particle(s) involved in the strong interaction. *[1]*

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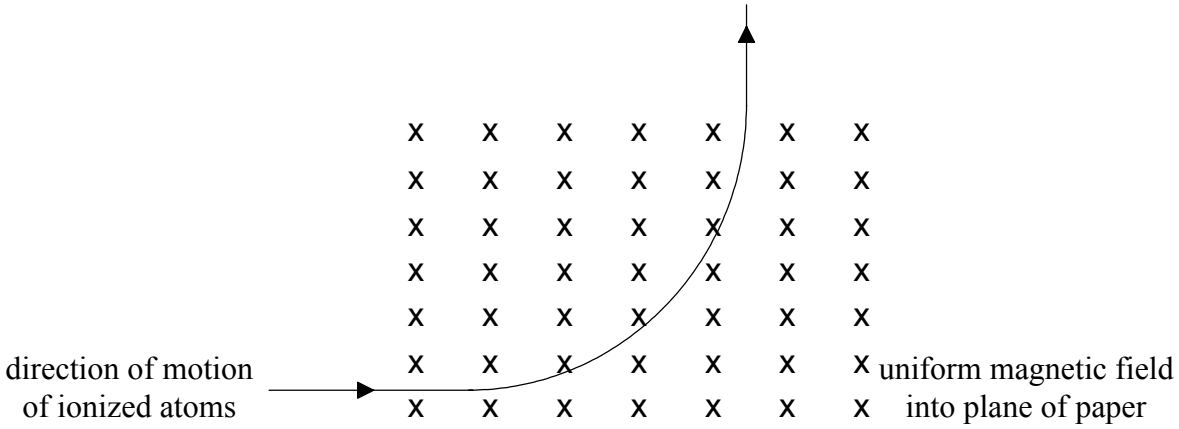
B3. This question is about charged particles in a magnetic field.

A beam of singly ionized atoms moving at speed v enters a region of magnetic field strength B as shown below.



The magnetic field is directed into the plane of the paper. The ions follow a circular path.

(a) Deduce that the radius r of the circular path is given by

$$r = \frac{mv}{Bq}$$

where m and q are the mass and charge respectively of the ions. *[2]*

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In one particular experiment, the beam contains singly ionized neon atoms all moving at the same speed. On entering the magnetic field, the beam divides in two. The path of the ions of mass 20 u has radius 15.0 cm.

(b) Calculate in terms of u, the mass of the ions having a path of radius 16.5 cm. *[2]*

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(This question continues on the following page)

(Question B3 continued)

The atomic number (proton number) of neon is 10.

(c) State the number of protons and neutrons in each type of neon ion. *[2]*

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Option C — Energy Extension

C1. This question is about wind turbines.

(a) State **two** factors that affect the maximum theoretical power output of a wind turbine. *[2]*

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A wind farm is to be built to supply electrical energy to a small town. The following data is available.

Energy consumption for the town for 1 year = 5.0×10^7 kWh
Length of turbine blade = 20.0 m
Average wind speed = 8.0 ms^{-1}
Density of air = 1.1 $kg\,m^{-3}$
1 year = 3.2×10^7 s

(b) Deduce from this data that approximately 16 wind turbines are required. *[5]*

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(c) State **three** reasons why in fact more than 16 turbines will be needed. *[3]*

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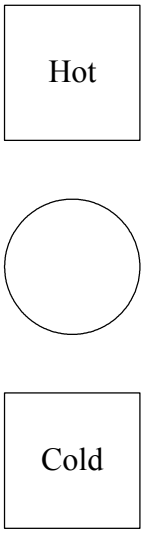
C2. This question is about heat engines.

Part of a schematic diagram for a heat engine is shown below.



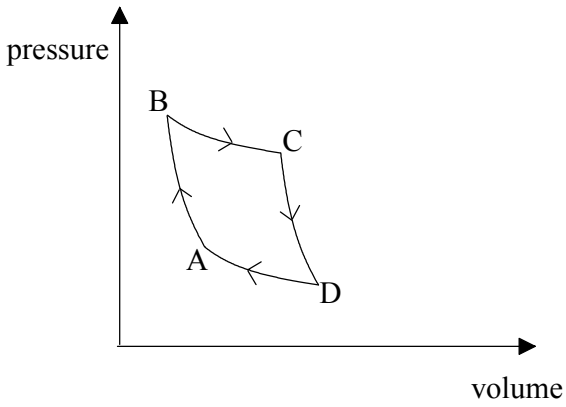
(a) On the diagram above draw and label arrows to represent the energy transfer paths for this engine. *[3]*

(This question continues on the following page)

(Question C2 continued)

The engine operates in a Carnot cycle.

The diagram below is a pressure-volume indicator diagram for one cycle of the engine.



For the stages A→B, B→C, C→D, D→A, of the cycle, state which stage(s) represent

(b) (i) an isothermal compression. *[1]*

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(ii) an adiabatic expansion. *[1]*

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(iii) work done on the engine. *[1]*

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(iv) thermal energy transfer to or from the engine. *[1]*

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(c) State how the total work done by the engine in one cycle may be calculated from the diagram. *[1]*

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(d) An electrical power station situated in northern Canada uses water to cool the steam as it leaves the turbine. Suggest why the efficiency of the turbine could be greater in winter than in summer. *[2]*

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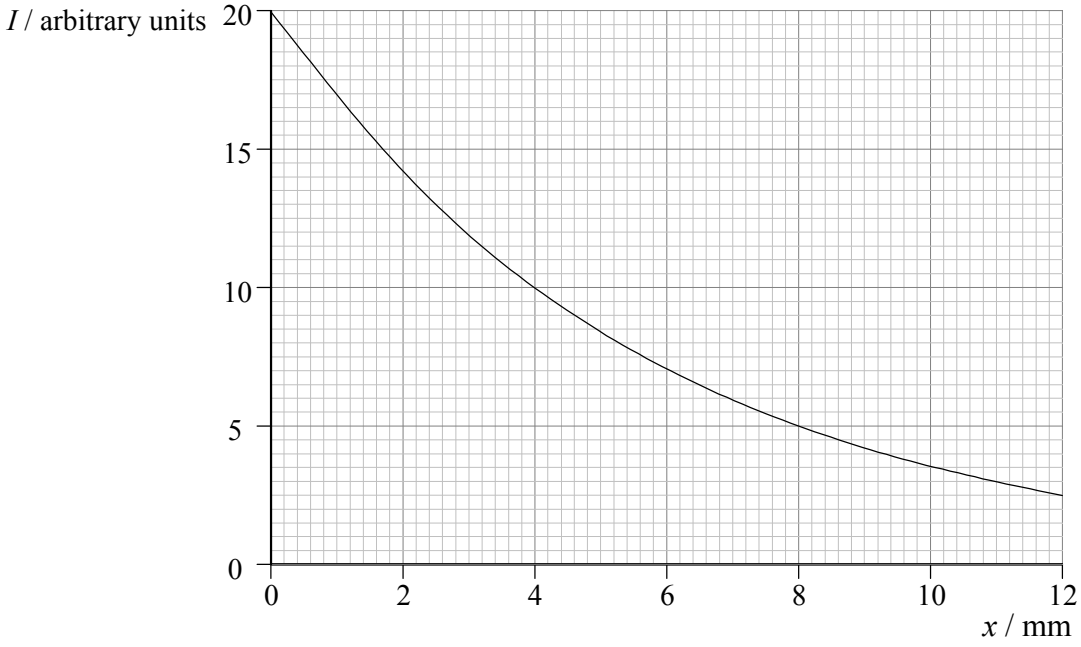
The graph below shows the variation of the intensity I of a parallel beam of X-rays after it has been transmitted through a thickness x of lead.



(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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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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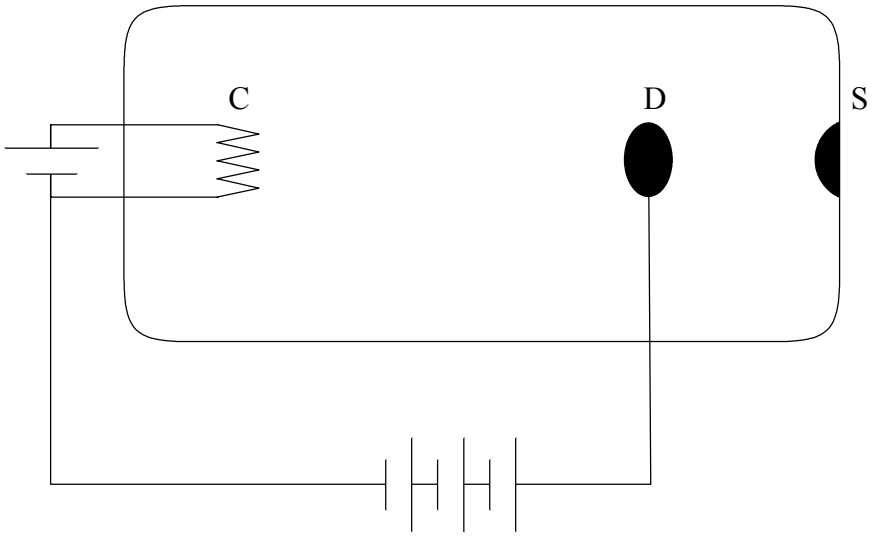
E3. This question is about cathode rays.

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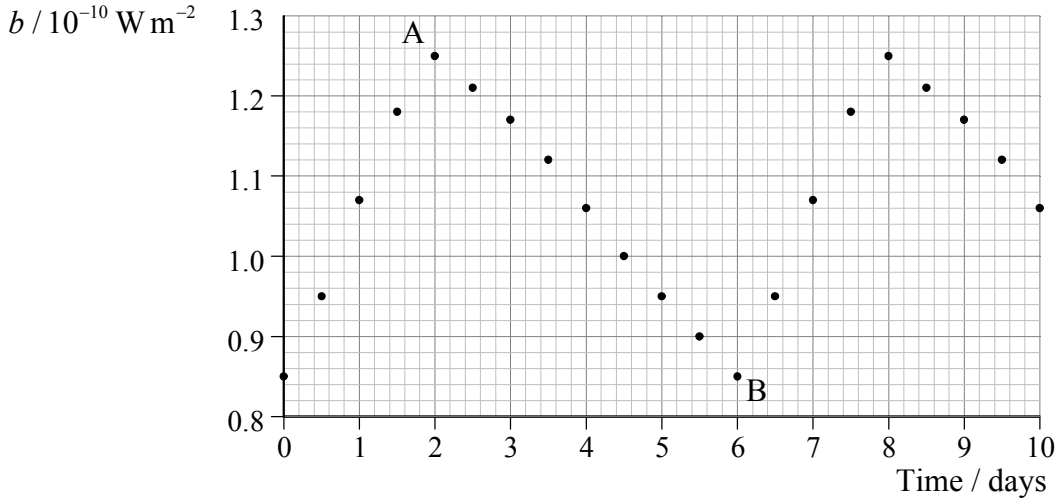
The variation with time t, of the apparent brightness b, of a Cepheid variable is shown below.



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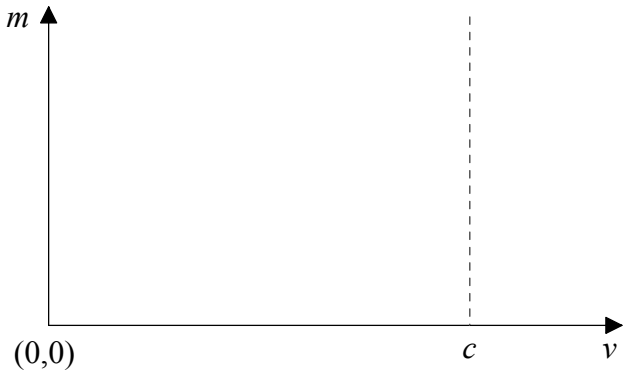
(b) On the axes below draw a sketch graph to show the variation of mass m with speed v for a particle called a muon whose rest mass is $106\,\text{MeV}\,c^{-2}$. *(This is a sketch graph; you do not need to put any values on the axes.)* *[2]*

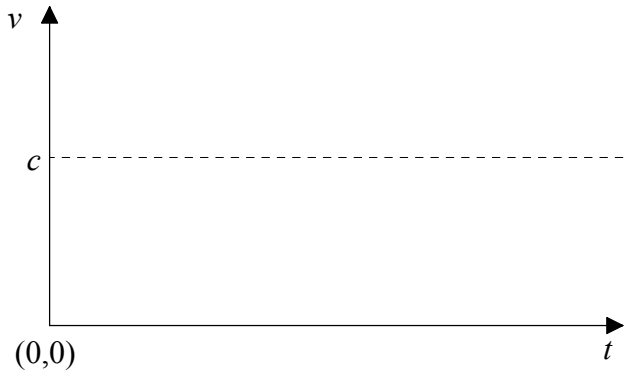


(c) A constant force acts on the muon. On the axes below draw a sketch graph to show the variation with time t, of the speed v of the muon according to

(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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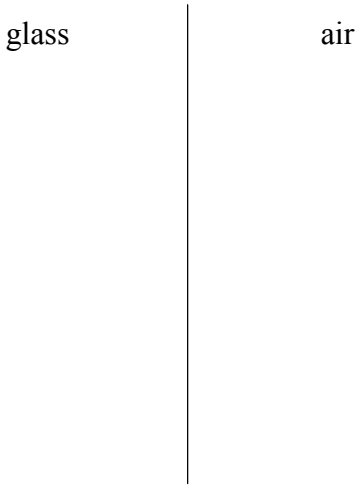
Option H — Optics

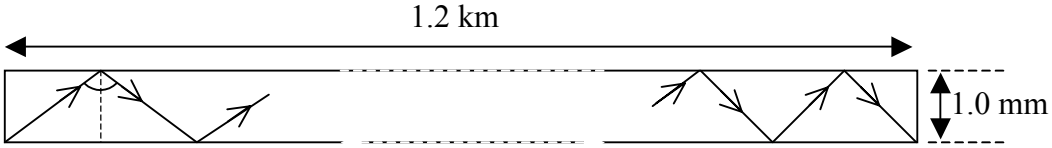
H1. This question is about refractive index and critical angle.

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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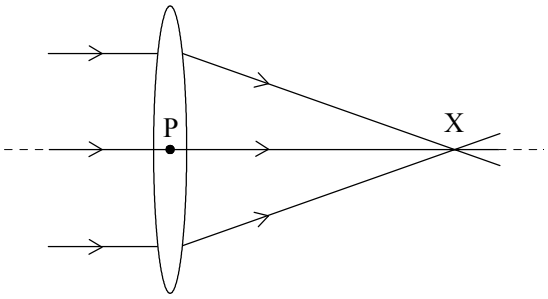
H2. This question is about lenses.

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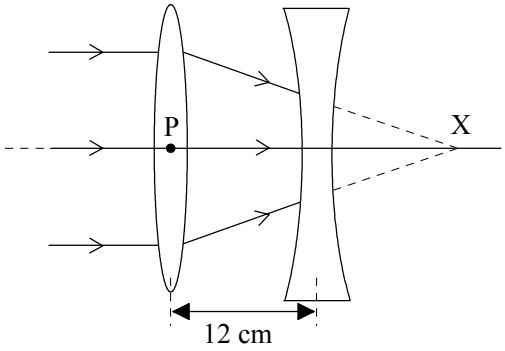
A diverging lens of focal length 24 cm is now placed 12 cm from the convex lens as shown below.



(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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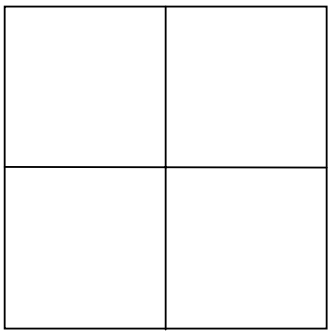
H3. This question is about spherical aberration.

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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