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

M03/430/H(3)+

PHYSICS
HIGHER LEVEL
PAPER 3

Candidate number

Tuesday 20 May 2003 (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. You may continue your answers on answer sheets. Write your candidate number on each answer sheet, and attach them to this examination paper and your cover sheet using the tag provided.
- At the end of the examination, indicate the letters of the Options answered in the candidate box on your cover sheet and indicate the number of answer sheets used in the appropriate box on your cover sheet.

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Option D – Biomedical physics

D1. This question is about scaling and looks at why it is dangerous for insects to fall into water.

(a) A sphere of radius r and mass M is completely immersed in water and then removed. A thin film of water of constant thickness sticks to the sphere. Assuming that the mass m of the film is proportional to the surface area of the sphere, deduce that $\frac{m}{M}$ is proportional to $\frac{1}{r}$. *[3]*

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For a sphere of radius 0.80 m, the above ratio $\frac{m}{M}$ is equal to 2 %.

A flying insect lands on the surface of water in a glass. It becomes immersed in the water but eventually manages to crawl on to the rim of the glass.

(b) (i) Assuming that the body of the insect can be approximated to a sphere of radius 4.0 mm, estimate the ratio of the mass of water carried out by the insect to its mass. *[3]*

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(ii) State **one** assumption that you have made in your estimation. *[1]*

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(iii) Comment on your answer to part b(i) above. *[1]*

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D2. This question is about ultrasound scanning.

(a) State a typical value for the frequency of ultrasound used in medical scanning. *[1]*

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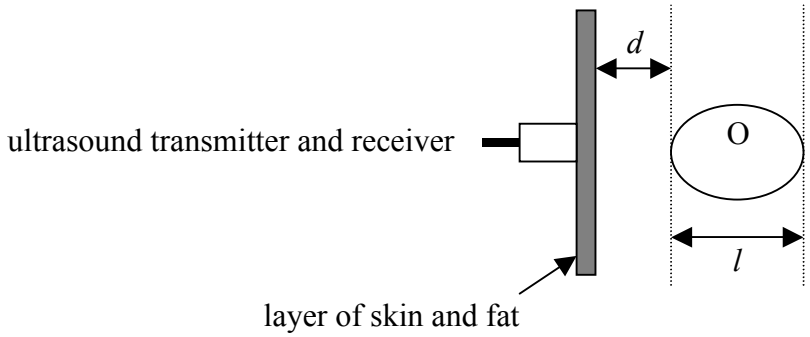
The diagram below shows an ultrasound transmitter and receiver placed in contact with the skin.



The purpose of this particular scan is to find the depth *d* of the organ labelled O below the skin and also to find its length, *l*.

(b) (i) Suggest why a layer of gel is applied between the ultrasound transmitter/receiver and the skin. *[2]*

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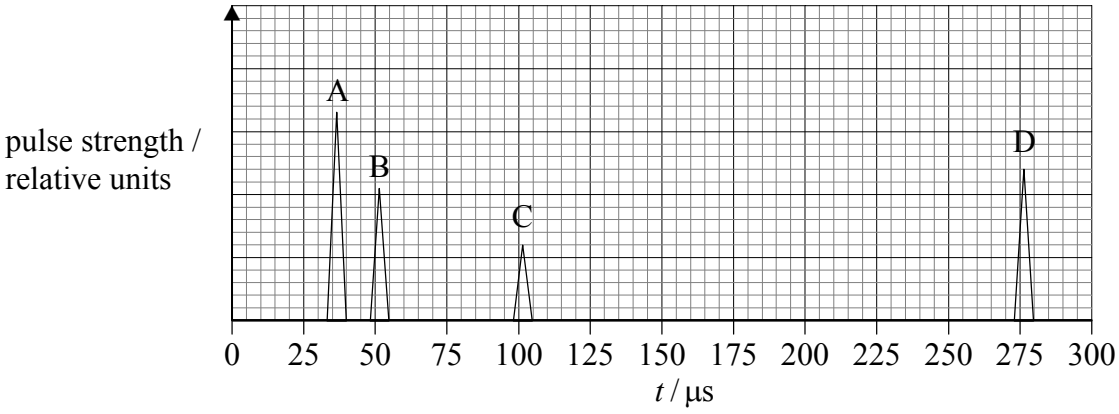
On the graph below the pulse strength of the reflected pulses is plotted against time *t* where *t* is the time lapsed between the pulse being transmitted and the time that the pulse is received.



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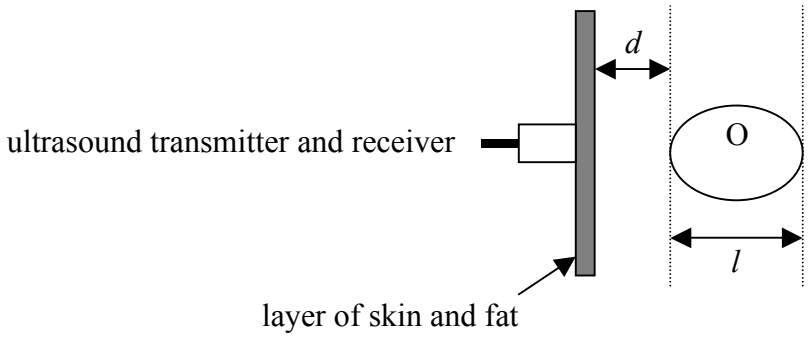
(Question D2(b) continued)

(ii) Indicate on the diagram below the origin of the reflected pulses A, B and C and D. *[2]*



(iii) The mean speed in tissue and muscle of the ultrasound used in this scan is $1.5\times10^{3}\ \mathrm{m\,s^{-1}}$. Using data from the above graph, estimate the depth *d* of the organ beneath the skin and the length *l* of the organ O. *[4]*

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(c) The above scan is known as an A-scan. State **one** way in which a B-scan differs from an A-scan. *[1]*

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(d) State **one** advantage and **one** disadvantage of using ultrasound as opposed to using X-rays in medical diagnosis. *[2]*

Advantage: . . . . . .

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Disadvantage: . . . . . .

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D3. This question is about energy from food.

(a) The calorific value of potatoes is $2.5\,\text{MJ}\,\text{kg}^{-1}$. Calculate the mass of potatoes that will yield the amount of energy that is equivalent to the energy gained by an object of mass 80 kg raised through a vertical height of 3000 m. *[2]*

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(b) State **one** reason why a person would need to eat much more than this calculated mass of potatoes in order to climb a mountain of height 3000 m. *[1]*

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D4. This question is about radiation used in medicine.

(a) Define the terms *exposure* and *absorbed dose*. *[2]*

Exposure: . . . . . .

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Absorbed dose: . . . . . .

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(b) Explain, with reference to α and γ radiation, the distinction between absorbed dose and dose equivalent. *[3]*

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(c) Explain why, when using radioactive tracer elements in the treatment of cancer, it is better to use radioactive isotopes that have a long physical half-life and a short biological half-life. *[2]*

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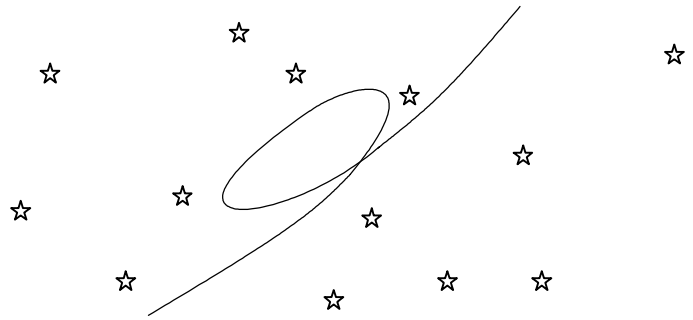
Option E – The history and development of physics

E1. This question is about the motion of Mars as observed from Earth.

The diagram below shows a sketch of the path of Mars as observed from Earth against the background of the fixed stars over a period of six months.



(a) State the name given to this type of observed motion. *[1]*

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(b) Outline how this observed motion of Mars was explained by

(i) Ptolemy. *[2]*

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(ii) Copernicus. *[2]*

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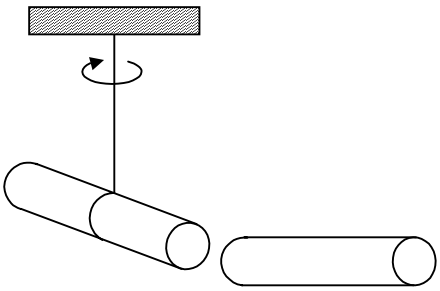
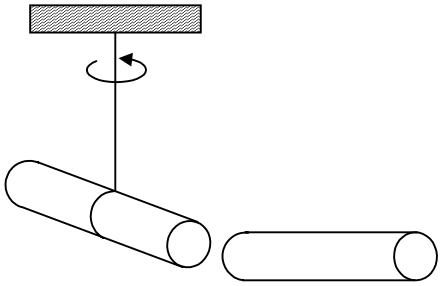
E2. This question is about electrification by contact.

In the Eighteenth Century, Benjamin Franklin demonstrated that there are two types of electricity produced by friction. He did this by using ebonite rods rubbed with fur and glass rods rubbed with silk. The diagram below shows two situations in which one of the rods is suspended vertically by a thread and another rod is brought up close to one end of the suspended rod. This causes the suspended rods to rotate. The direction of rotation of the suspended rod in each situation is shown.

Situation 1



Situation 2



(a) For each situation, identify possible types of rod (ebonite **or** glass) by labelling them using the letter E for the ebonite rods and the letter G for the glass rods. *[2]*

(b) Franklin called the two types of electricity *positive* and *negative*. Suggest why he gave them these names. *[2]*

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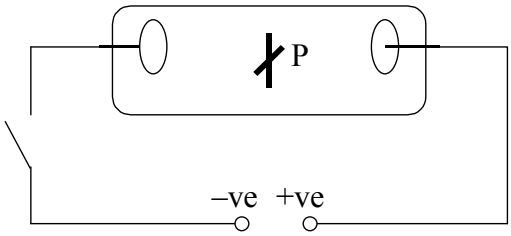
(Question E2 continued)

(c) Complete the table below to show how Franklin's theory about the nature of electricity and how modern atomic theory can be used to explain the phenomenon demonstrated by the diagram in part (a). *[6]*

	Hypothesis / theory	**Explanation**
Franklin	. . . . .	. . . . .
Modern atomic theory	. . . . .	. . . . .

E3. This question is about cathode rays.

The diagram below shows a discharge tube that contains air at low pressure. A cross-shaped object P is placed between the electrodes.



high-voltage supply

When the supply is switched on a greenish glow is seen coming from the tube. The object P also casts a distinct shadow.

(a) Mark on the diagram the region where this shadow appears. *[1]*

(b) In 1876, Eugen Goldstein proposed that such shadows are caused by *cathode rays*.

(i) Explain why Goldstein used this term. *[1]*

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(ii) In 1895, Jean Baptiste Perrin showed that the sign of the electric charge carried by these rays is negative. Describe, using the diagram above, how he managed to do this. *[2]*

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(iii) State the actual nature of cathode rays. *[1]*

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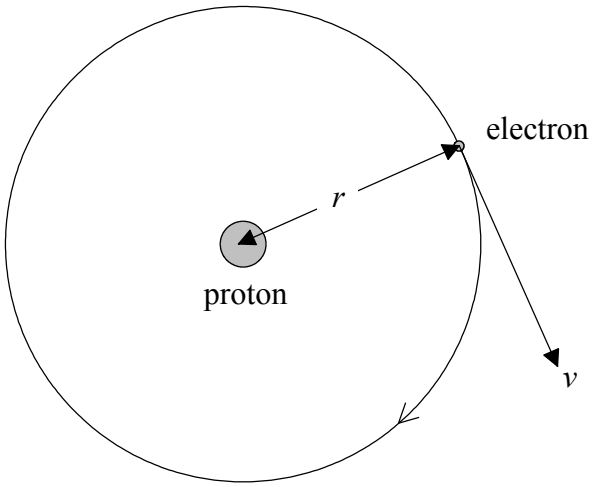
E4. This question is about models of the hydrogen atom.

In 1913 Neils Bohr published his theory of the hydrogen atom in which he proposed that an electron orbited a proton as illustrated in the diagram below.



The theory includes two postulates known as the *Bohr Postulates*.

If the radius of orbit of electron is r and its orbital speed is v, the first Bohr postulate may be expressed mathematically as:

$$mvr = \frac{nh}{2\pi}$$

where m is the mass of the electron.

According to this postulate, the electron can move only in orbits defined by $n = 1, 2, 3$ *etc*. Bohr called these allowed orbits *stable orbits*.

(a) Explain why Bohr called the allowed orbits *stable orbits* and explain why such orbits are in contradiction to Classical Electromagnetic Theory. *[2]*

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(This question continues on the following page)

(Question E4 continued)

The second Bohr postulate may be stated mathematically as shown below.

$$E_{n_2} - E_{n_1} = hf$$

(b) Explain, with reference to the term n used in the first postulate, the following terms. *[4]*

E_{n_2} . . . . . .

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E_{n_1} . . . . . .

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Using both postulates, Bohr was able to derive the *Rydberg equation*. This equation may be written as shown below.

$$\frac{1}{\lambda} = R_H \left(\frac{1}{n^2} - \frac{1}{m^2} \right)$$

When $n = 2$ this equation enables the values of the wavelengths in the Balmer spectral series to be determined.

(c) If $R_H = 1.1 \times 10^7 \text{ m}^{-1}$, determine the value of the longest wavelength present in the Balmer series. *[2]*

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(d) State **two** ways in which the model of the hydrogen atom proposed by Schrödinger differs from the model proposed by Bohr. *[2]*

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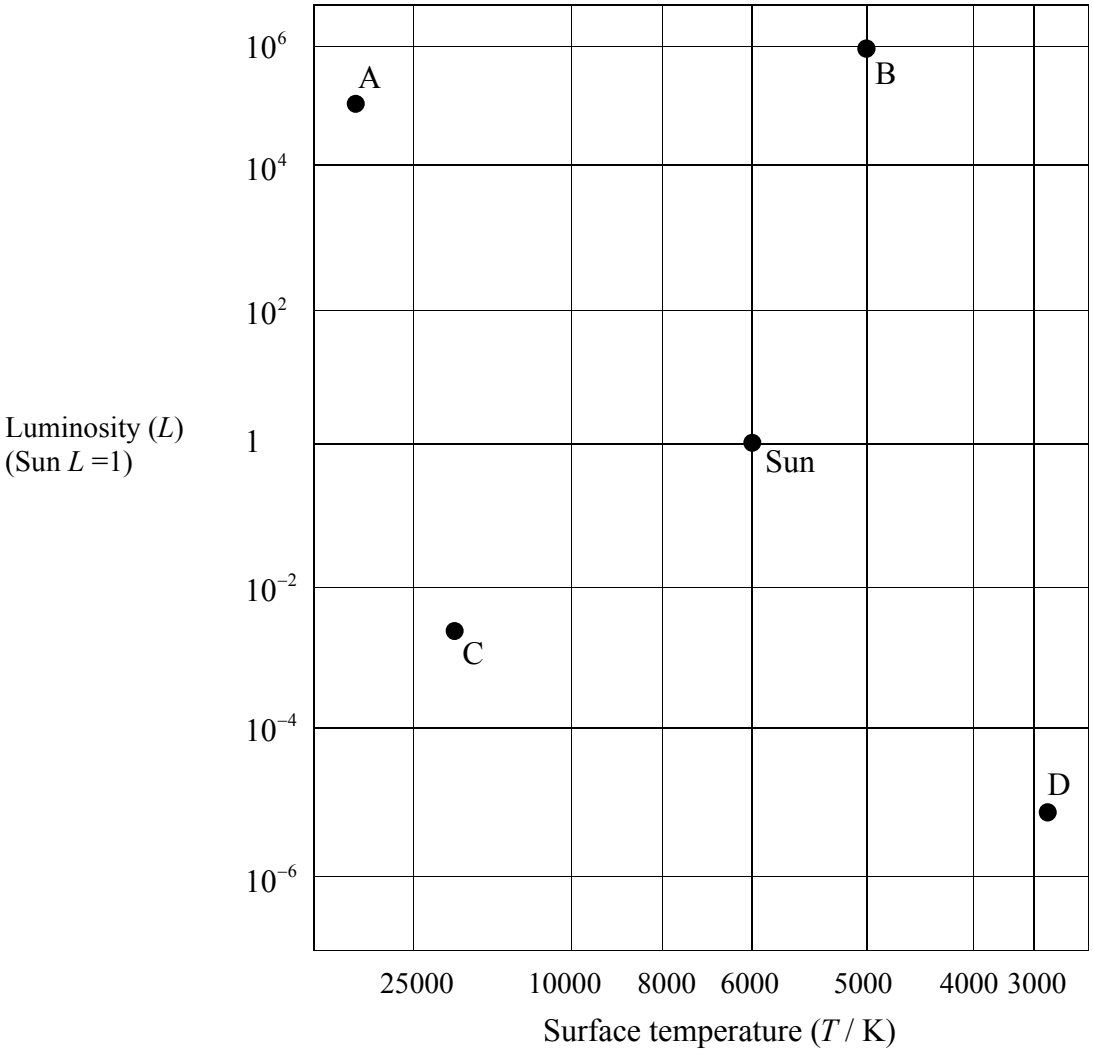
Option F – Astrophysics

F1. This question is about the nature of certain stars on the Hertzsprung-Russell diagram and determining stellar distance.

The diagram below shows the grid of a Hertzsprung-Russell (H-R) diagram on which the positions of the Sun and four other stars A, B, C and D are shown.



(a) State an alternative labelling of the axes.

(i) *x*-axis . . . . . *[1]*

(ii) *y*-axis . . . . . *[1]*

(This question continues on the following page)

(Question F1 continued)

(b) Complete the table below. *[4]*

Star	Type of star
A	
B	
C	
D	

(c) Explain, using information from the H-R diagram, and without making any calculations, how astronomers can deduce that star **B** is larger than star **A**. *[3]*

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(d) Using the following data and information from the H-R diagram, show that star **B** is at a distance of about 700 pc from Earth. *[4]*

Apparent visual brightness of the Sun $= 1.4\times10^{3}$ W m^{-2}
Apparent visual brightness of star B $= 7.0\times10^{-8}$ W m^{-2}
Mean distance of the Sun from Earth = 1.0 AU
1 parsec $= 2.1\times10^{5}$ AU

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(e) Explain why the distance of star **B** from Earth cannot be determined by the method of stellar parallax. *[1]*

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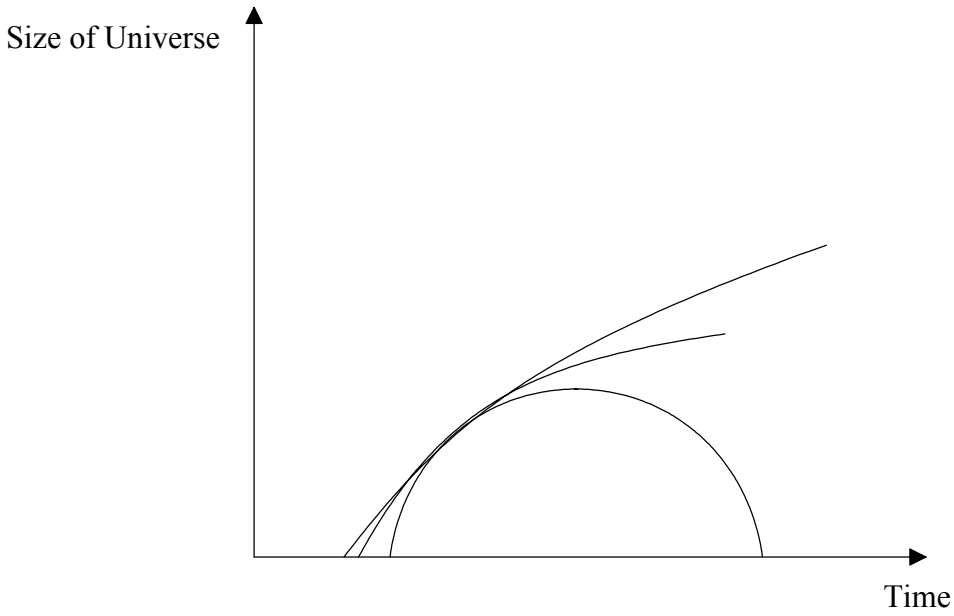
F2. This question is about the possible evolution of the Universe.

The diagram below is a sketch graph that shows three possible ways in which the size of the Universe might change with time.



Depending on which way the size of the Universe changes with time, the Universe is referred to either being *open* or *flat* or *closed*.

(a) On the diagram, identify each type of Universe. *[3]*

(b) Complete the table below to show how the mean density ρ of each type of Universe is related to the critical density ρ_0. *[3]*

Type of Universe	Relation between ρ and ρ_0
Open	
Flat	
Closed	

F3. This question is about white dwarfs and neutron stars.

(a) State the property that determines whether a star ends its life as a white dwarf **or** as a neutron star. *[1]*

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(b) Define the *Chandrasekhar limit* and use this concept to explain the difference between a white dwarf and neutron star. *[3]*

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(c) State the name given to a rotating neutron star. *[1]*

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F4. This question is about galactic redshift, the Hubble constant and the age of the Universe.

(a) State how the observed redshift of light from many distant galaxies is explained. *[1]*

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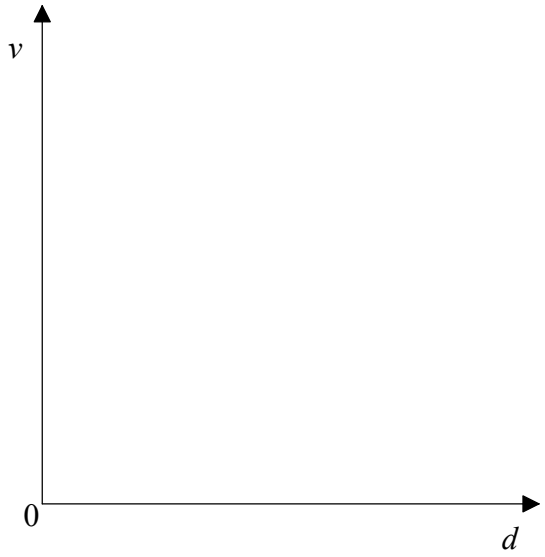
(b) Using the axes below sketch a graph to show how the recessional speed v between galaxies varies with the distance d between them. *(Please note this is a sketch graph; you do not need to add any numerical values.)* *[1]*



(c) State how the Hubble constant is determined from such a graph. *[1]*

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(d) A value for the Hubble constant is $100\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$. Use this value to estimate the age of the Universe in years. (1 Mpc $\approx 3\times10^{19}$ km, 1 year $\approx 3\times10^{7}$ s) *[2]*

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Option G – Relativity

G1. This question is based upon a thought experiment first proposed by Einstein.

(a) Define the terms *proper time* and *proper length*. *[2]*

Proper time: . . . . . .

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Proper length: . . . . . .

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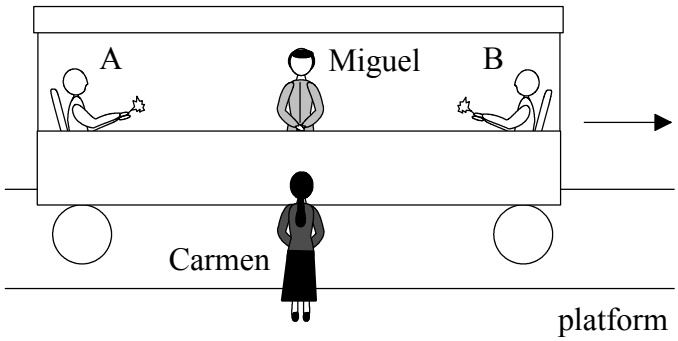
In the diagram below Miguel is in a railway carriage that is travelling in a straight line with uniform speed relative to Carmen who is standing on the platform.

Miguel is midway between two people sitting at opposite ends A and B of the carriage.



At the moment that Miguel and Carmen are directly opposite each other, the person at end A of the carriage strikes a match as does the person at end B of the carriage.

According to Miguel these two events take place simultaneously.

(b) (i) Discuss whether the two events will appear to be simultaneous to Carmen. *[4]*

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(This question continues on the following page)

(Question G1(b) continued)

(ii) Miguel measures the distance between A and B to be 20.0 m. However, Carmen measures this distance to be 10.0 m. Determine the speed of the carriage relative to Carmen. *[2]*

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(iii) Explain which of the **two** observers, if either, measures the correct distance between A and B? *[2]*

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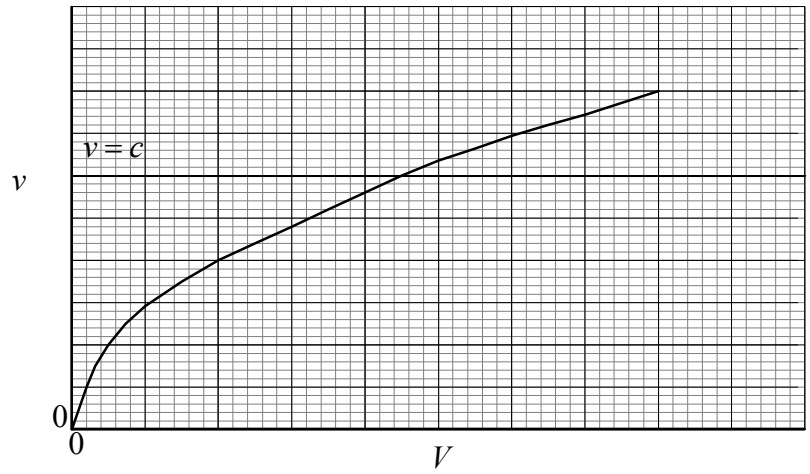
G2. This question is about electrons travelling at relativistic speeds.

A beam of electrons is accelerated in a vacuum through a potential difference V.

The sketch-graph below shows how the speed v of the electrons, as determined by non-relativistic mechanics, varies with the potential V, (relative to the laboratory). The speed of light c is shown for reference.



(a) On the grid above, draw a graph to show how the speed of the electrons varies over the same range of V as determined by relativistic mechanics. *[2]*
(Note this is a sketch-graph; you do not need to add any values)

(b) Explain briefly, the general shape of the graph that you have drawn. *[3]*

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(c) When electrons are accelerated through a potential difference of 1.50×10^6 V, they attain a speed of $0.97c$ relative to the laboratory.

Determine, for an accelerated electron,

(i) its mass. *[3]*

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(ii) its total energy. *[2]*

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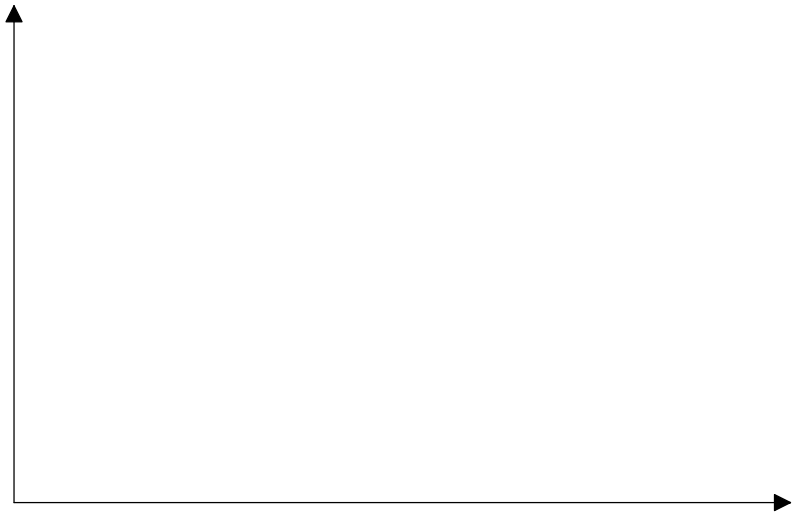
G3. This question is about spacetime, gravity and black holes.

(a) In both the Special and General Theories of Relativity, Einstein introduced the idea of *spacetime*.

Consider a particle that is a long way from any large mass. The particle is moving with constant velocity in the x-direction.

Use this example and the axes below to describe what is meant by *spacetime*. *[3]*



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(Question G3 continued)

(b) The Theory of General Relativity suggests, at distances a long way from large masses, spacetime is flat. The effect of large masses is to warp spacetime. Explain briefly how Einstein used this idea to describe, for example, the gravitational attraction between the Earth and an orbiting satellite. *[3]*

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(c) Describe what is meant by a *black hole*. *[2]*

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(d) Estimate the radius of the Sun for it to become a black hole. (Mass of the Sun $\approx 2\times10^{30}$ kg) *[2]*

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Option H – Optics

H1. This question is about refraction.

(a) With the aid of a suitable diagram define the term *refractive index* as applied to an optical material. *[2]*

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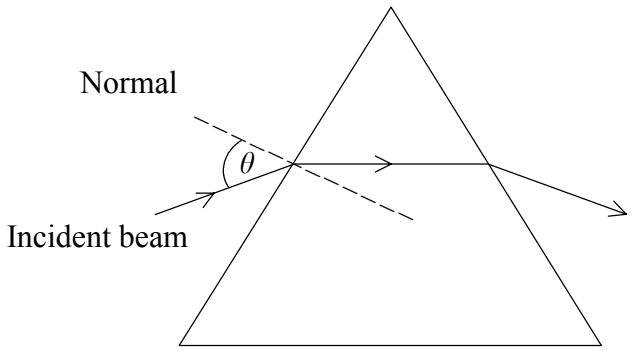
The diagram below shows the path followed by a ray of red light that is incident on one face of a glass prism at an angle θ to the normal.



(b) (i) The red light is now replaced by blue light. On the diagram sketch the corresponding path followed by a ray of blue light incident at the same angle θ. *[3]*

(ii) State and explain whether the refractive index for red light in the glass is greater than, equal to or less than the refractive index for blue light. *[1]*

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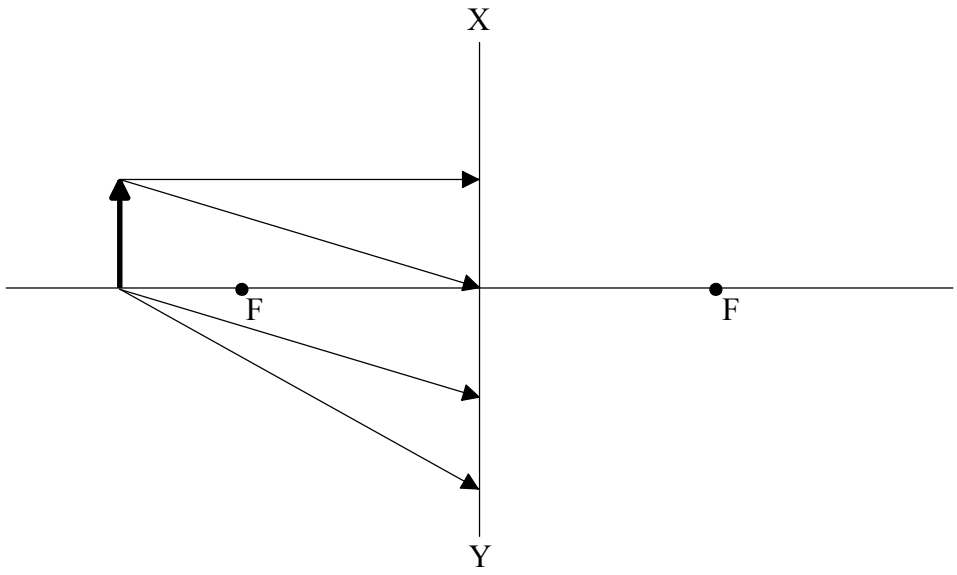
H2. This question is about a concave (diverging) lens.

The diagram below shows four rays of light from an object O that are incident on a thin **concave** (**diverging**) lens. The *focal points* of the lens are shown labelled F. The lens is represented by the straight line XY.



(a) Define the term *focal point*. *[2]*

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(b) On the diagram,

(i) complete the paths of the four rays in order to locate the position of the image formed by the lens. *[4]*

(ii) show where the eye must be placed in order to view the image. *[1]*

(c) State and explain whether the image is real **or** virtual. *[2]*

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(This question continues on the following page)

(Question H2 continued)

(d) The focal length of the lens is 50.0 cm. Determine the linear magnification of an object placed 75.0 cm from the lens. *[3]*

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(e) Half of the lens is now covered such that only rays on one side of the principal axis are incident on the lens. Describe the effects, if any, that this will have on the linear magnification and the appearance of the image. *[2]*

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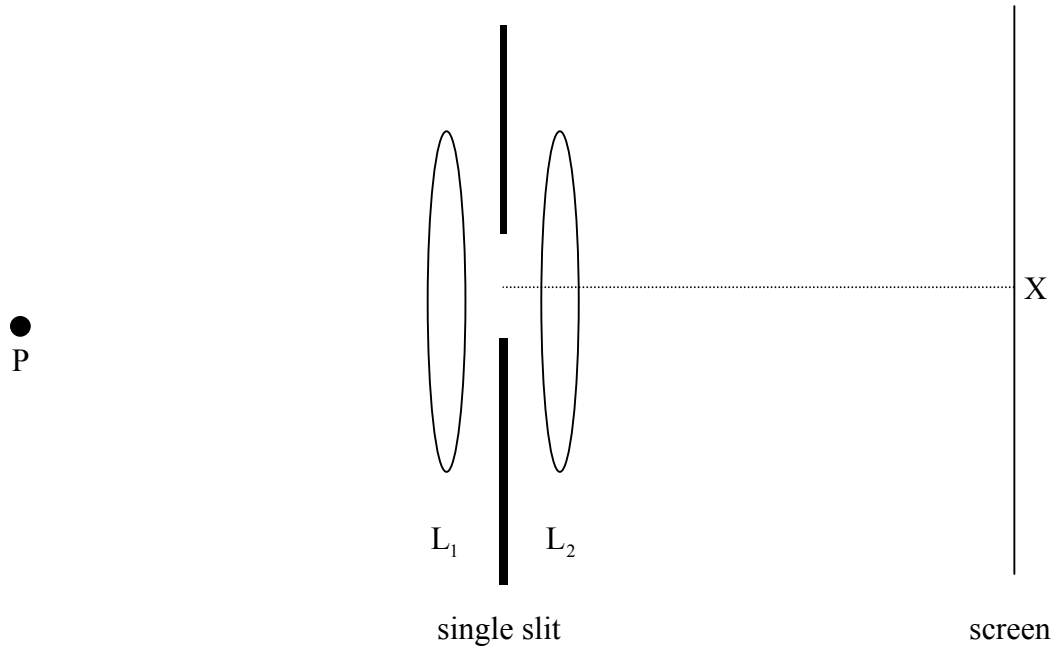
H3. This question is about single slit diffraction.

The diagram below shows an experimental arrangement for observing Fraunhofer diffraction by a single slit. After passing through the convex lens L_1, monochromatic light from a point source P is incident on a narrow, rectangular single slit. After passing through the slit the light is brought to a focus on the screen by the lens L_2. The point source P is at the focal point of the lens L_1.



The point X on the screen is directly opposite the central point of the slit.

(a) Explain qualitatively how Huygen's principle accounts for the phenomenon of single slit diffraction. *[2]*

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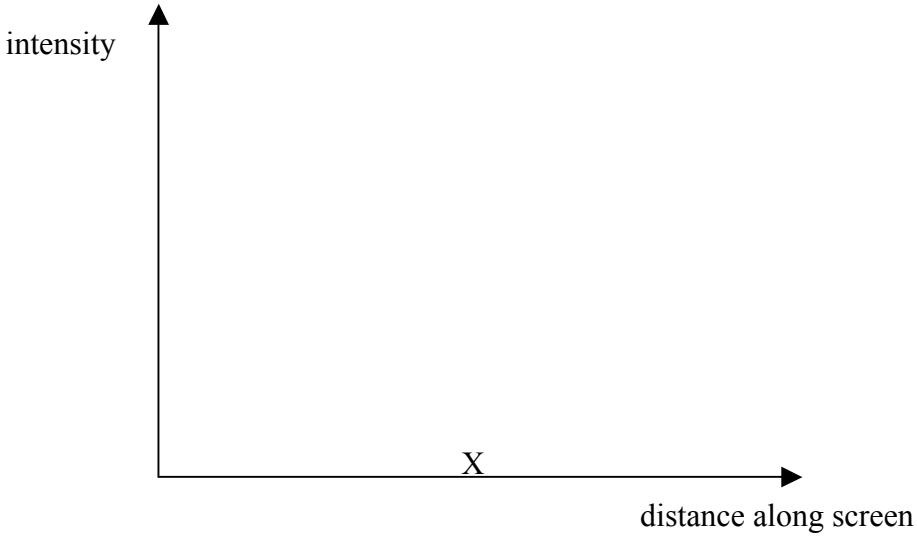
(Question H3 continued)

(b) Using the axes below draw a graph to show how the intensity of the pattern varies with distance along the screen. The point X on the screen is shown as a reference point. *(This is a sketch graph; you do not need to add any numerical values.)* *[3]*



(c) In this experiment the light has a wavelength of 500 nm and the width of the central maximum of intensity on the screen is 10.0 mm. When light of unknown wavelength λ is used, the width of the central maximum of intensity is 13.0 mm. Determine the value of λ. *[2]*

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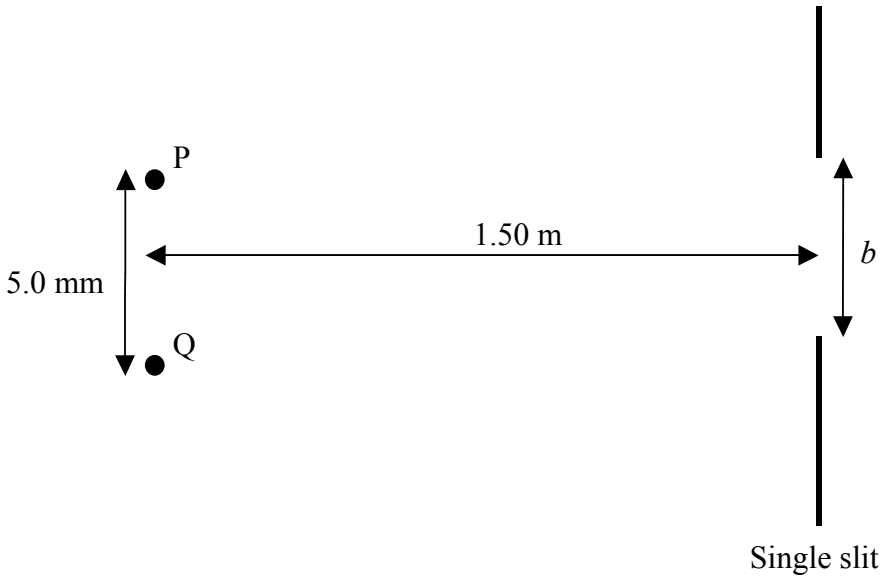
(This question continues on the following page)

(Question H3 continued)

The lens L_1 is now removed and another point source Q emitting light of the same wavelength as P (500 nm) is placed 5.0 mm from P and the two sources are arranged as shown below.



The distance between the sources and the slit is 1.50 m.

(d) (i) State the condition for the image of P and the image of Q formed on the screen to be just resolved. *[1]*

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(ii) Determine the minimum width *b* of the slit for the two images to be just resolved. *[2]*

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