IB DIPLOMA PROGRAMME
PROGRAMME DU DIPLÔME DU BI
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N06/4/PHYSI/HP3/ENG/TZ0/XX+

88066503

PHYSICS
HIGHER LEVEL
PAPER 3

Monday 6 November 2006 (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.

0132

Option D — Biomedical Physics

D1. This question is about scaling.

Two insects have the same shape. The linear dimensions of insect A are 2.0 times the linear dimensions of insect B.

(a) Calculate the ratio

(i) $\frac{\text{surface area of insect A}}{\text{surface area of insect B}}$. *[1]*

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(ii) $\frac{\text{volume of insect A}}{\text{volume of insect B}}$. *[1]*

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(b) The absorption of oxygen by insects depends on their surface areas. The amounts of oxygen needed depend on the volumes of the insects. Use your answers in (a) to suggest why these conditions limit the size of insects. *[2]*

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D2. This question is about sound intensity levels.

(a) Distinguish between *sound intensity* and *loudness*. *[2]*

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(b) An engine generates 2.4 W of sound power that is emitted uniformly in all directions. For health reasons, the intensity level at the ear must not exceed 82 dB. Calculate the minimum distance that any person must be from the engine unless wearing ear protection. (The surface area of a sphere of radius r is $4\pi r^2$) *[5]*

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D3. This question is about X-rays.

A parallel beam of X-rays is used to investigate a broken bone. The attenuation coefficient for soft tissue (muscle) is $0.035\,\text{cm}^{-1}$. The X-ray half-value thickness for bone is about 150 times less than that for soft tissue.

(a) Define the term *half-value thickness*. *[1]*

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(b) Deduce that the attenuation coefficient for bone is $5.3\ \text{cm}^{-1}$. *[2]*

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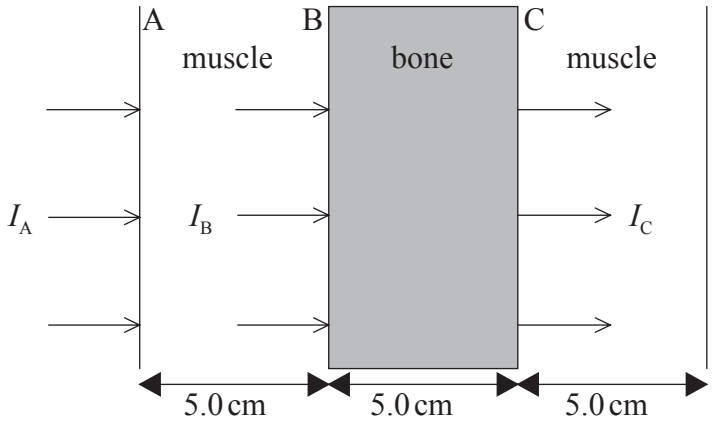
(This question continues on the following page)

(Question D3 continued)

(c) A parallel beam of X-rays is incident on the leg of a person. The leg has a bone of diameter 5.0 cm, surrounded by muscle on each side of thickness 5.0 cm. A section through the leg is shown in the diagram below.



The intensity of the X-ray beam at the surface A of the leg is I_A. At the surface B of the bone, the intensity is I_B and the intensity of the beam emerging at surface C of the bone is I_C.

Calculate the ratio

(i) $\frac{I_B}{I_A}$. *[2]*

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(ii) $\frac{I_C}{I_B}$. *[1]*

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(d) Use your answer in (c) to explain how it is possible to obtain a shadow image of the leg and bone. *[3]*

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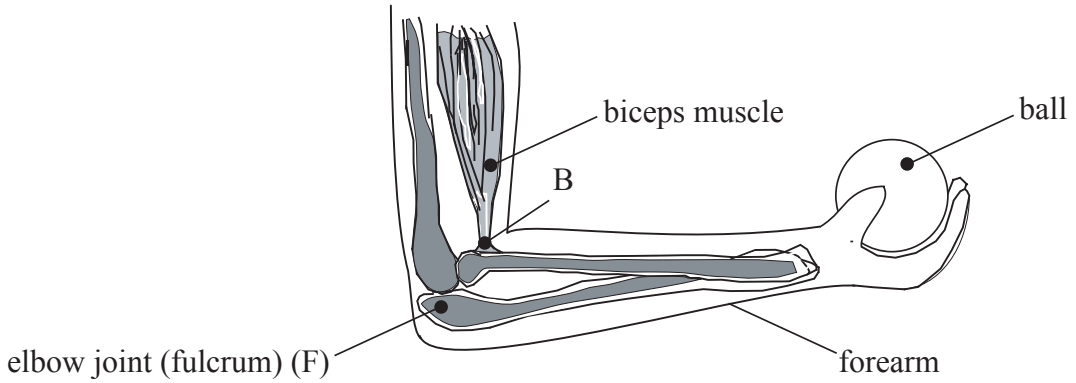
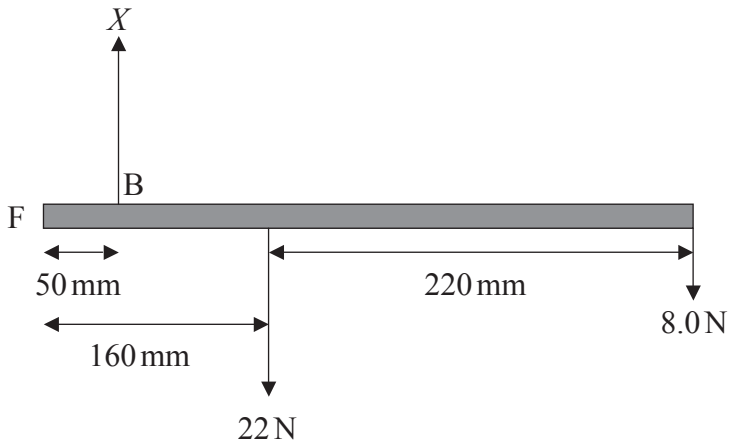
D4. This question is about the lever action of the forearm.

The diagram below shows the arm of a person who is holding a ball with the forearm horizontal.



The weight of the forearm is 22 N and the weight of the ball is 8.0 N.

The diagram below shows a representation of the lever system of the arm. The relevant forces and distances are shown. *X* is the force that the biceps muscle exerts on the rigid forearm.



(a) By taking moments about F, deduce that the magnitude of force *X* is 130 N. *[1]*

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(b) Deduce that for a small vertical movement of B, the velocity (movement) ratio is 0.13. *[1]*

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(This question continues on the following page)

(Question D4 continued)

(c) The efficiency of a lever is given by the expression

$$\text{efficiency} = \frac{\text{mechanical advantage}}{\text{velocity ratio}}.$$

Calculate the efficiency of this arm lever system. *[2]*

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(d) Explain why the forearm lever system is not 100 % efficient. *[1]*

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D5. This question is about dosimetry.

(a) Define the term *absorbed dose*. *[1]*

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(b) Explain what is meant by *quality factor* (relative biological effectiveness). *[2]*

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(c) The radioactive isotope potassium-40 occurs naturally in the body. Use the data below to calculate the annual dose equivalent that the body receives from the decay of potassium-40 within the body. *[2]*

number of atoms of potassion-40 per kilogram of the body	$= 8.0 \times 10^{18}$
decay constant of potassium-40	$= 5.3 \times 10^{-10}$ year^{-1}
energy absorbed by the body from the decay of one atom of potassium-40	$= 4.0 \times 10^{-14}$ J
quality factor of the radiation from decay of potassium-40	$= 1$

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Option E — The History and Development of Physics

E1. This question is about models of the universe.

(a) When viewed over a period of several years, the Moon and Mars both appear to move relative to the background of the fixed stars. Compare the observed motion of the Moon to that of Mars. *[3]*

Moon:

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Mars:

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(This question continues on the following page)

(Question E1 continued)

(b) Ptolemy was able to describe precisely and account for the differences in observed motion of the Moon and Mars. Describe the model developed by Ptolemy. *[4]*

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(c) According to Aristotle, the orbital motion of the planets is a natural motion. Outline how Newton's understanding of orbital motion of the planets differed from that of Aristotle. *[2]*

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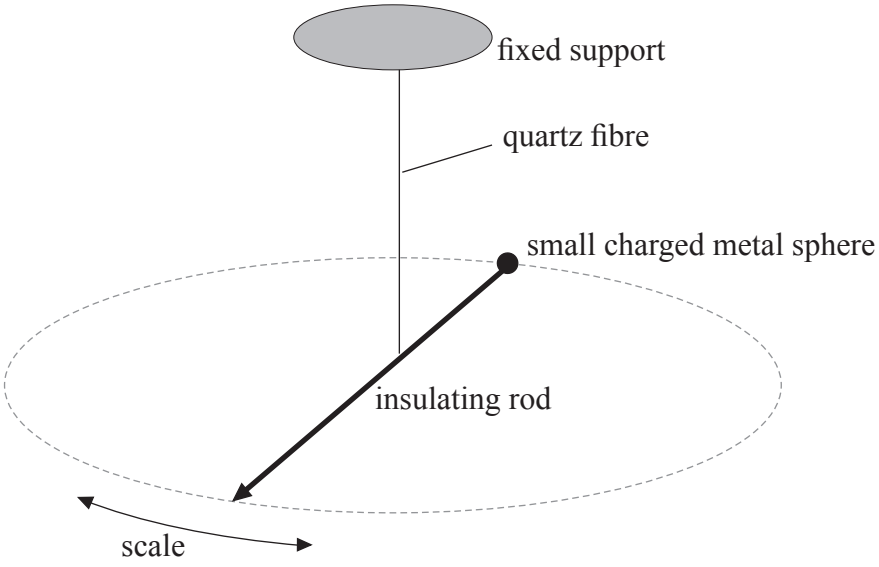
E2. This question is about the force between electrical charges.

The diagram below shows some apparatus, similar to that used by Coulomb, to establish the relation between the force between point charges and their separation.



(a) With the aid of the diagram above, outline how the apparatus may be used to determine the relation between the force between the charges and the separation of the charges. *[4]*

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(b) By knowing the ratio of the charges on the two spheres, Coulomb also established the relation between force and magnitude of charges. Explain how Coulomb determined these ratios. *[2]*

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E3. This question is about cathode rays.

(a) By means of a labelled sketch diagram, outline the discovery of cathode rays. *[3]*

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(b) Describe how cathode rays were shown to be charged particles. *[2]*

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E4. This question is about the spectrum of atomic hydrogen and Bohr theory.

In 1890 Johannes Rydberg discovered an empirical formula that enabled the wavelengths of the light in the atomic line spectrum of hydrogen to be calculated. The formula is

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

where λ is the wavelength, n and m are integers and R_{H} is the Rydberg constant.

In 1913 Niels Bohr published his theory of the hydrogen atom. This theory enabled the Rydberg formula to be derived. His theory also showed that the energy levels E_{n} of the hydrogen atom are given by the formula

$$E_{\mathrm{n}} = \frac{2.2\times10^{-18}}{n^2}$$

where E_{n} is measured in joules.

(a) Explain the significance, based on Bohr's theory, of the integers n and m in the above formulae. *[3]*

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(This question continues on the following page)

(Question E4 continued)

(b) Using the formulae in (a)

(i) estimate the wavelength of the spectral line that has the lowest value of wavelength in the atomic hydrogen line spectrum. *[2]*

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(ii) determine a value for the Rydberg constant. *[2]*

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E5. This question is about the de Broglie hypothesis and the uncertainty principle.

According to the de Broglie hypothesis, all particles have an associated wavelength that is related to the momentum of the particle.

By considering a particle that has a precisely defined wavelength, describe how the de Broglie hypothesis relates to the Heisenberg uncertainty principle. *[3]*

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Option F — Astrophysics

F1. (a) State where in the solar system, with respect to the planetary orbits, the greatest concentration of asteroids is found. *[1]*

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(b) Some constellations are not visible in the night sky for the whole of the year. Suggest **one** reason for this observation. *[2]*

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F2. This question is about stellar observations.

(a) Define the following terms.

(i) *Luminosity* *[1]*

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(ii) *Apparent brightness* *[1]*

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(b) The spectrum and temperature of a certain star are used to determine its luminosity to be approximately 5.0×10^{31} W. The apparent brightness of the star is 1.4×10^{-9} W m^{-2}. These data can be used to determine the distance of the star from Earth.

(i) State the name of this technique used to determine distances to stars. *[1]*

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(ii) Calculate the distance of the star from Earth in parsec. *[3]*

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(This question continues on the following page)

(Question F2 continued)

(c) Distances to some stars can be measured by using the method of stellar parallax.

(i) Outline this method. *[4]*

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(ii) Modern techniques enable stellar parallax angles as small as 5.0×10^{-3} arc-second to be measured. Calculate the maximum distance that can be measured using the method of stellar parallax. *[1]*

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F3. This question is about cosmology.

(a) Describe the observational evidence in support of an expanding universe. *[2]*

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(b) Define the term *critical density* of the universe. *[1]*

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(c) Discuss the significance of comparing the density of the universe to the critical density for determining the future of the universe. *[3]*

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F4. This question is about the Hubble constant.

(a) The value of the Hubble constant H_0 is accepted by some astronomers to be in the range $60\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$ to $90\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$.

(i) State and explain why it is difficult to determine a precise value of H_0. *[2]*

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(ii) State **one** reason why it would be desirable to have a precise value of H_0. *[1]*

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(b) The line spectrum of the light from the quasar 3C 273 contains a spectral line of wavelength 750 nm. The wavelength of the same line measured in the laboratory is 660 nm.

Using a value of H_0 equal to $75\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$, estimate the distance of the quasar from Earth. *[3]*

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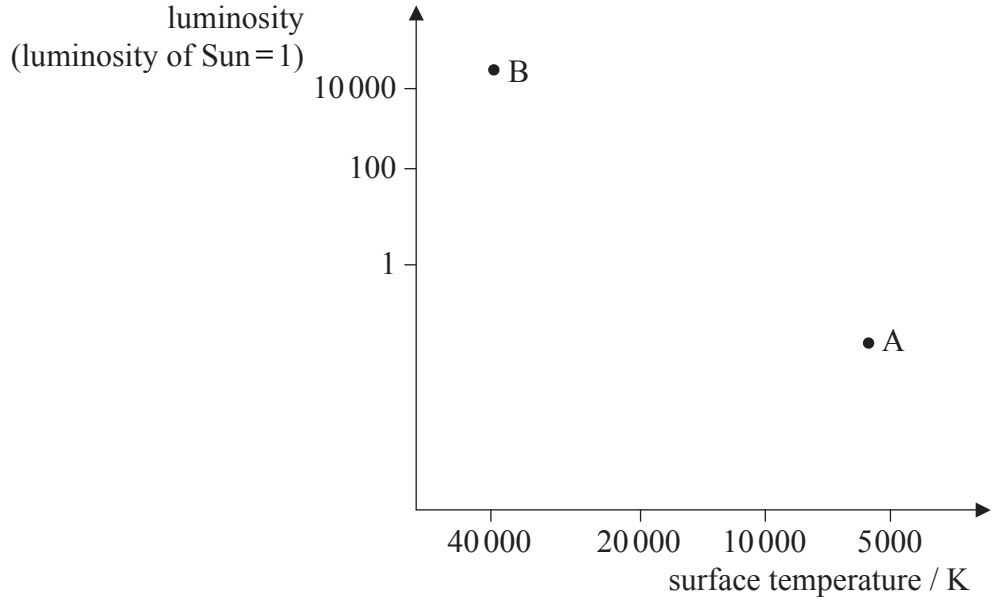
F5. This question is about two different stars.

The diagram below shows the position of two main-sequence stars A and B with respect to the labelled axes of a Hertzsprung-Russell diagram.



(a) Suggest which of the stars has the larger mass. *[2]*

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(b) State **one** difference between the changes in nucleosynthesis that take place in star B compared to star A after both stars leave the main sequence. *[1]*

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(c) On the diagram above, mark with the letter X, the approximate final position of star A after it has left the main sequence. *[1]*

Option G — Relativity

G1. This question is about relativistic kinematics and mechanics.

(a) Explain what is meant by an *inertial frame of reference*. *[2]*

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(b) State the **two** postulates of Special Relativity. *[3]*

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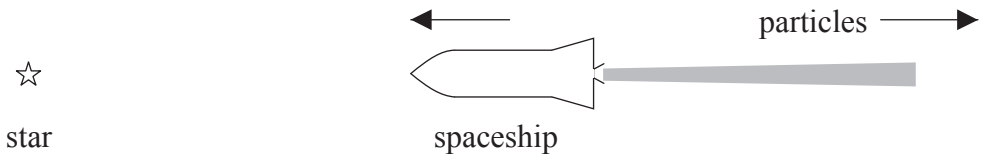
(c) A spaceship with a proper length of 240 m is travelling towards a star with a speed of 0.80c relative to the star. The exhaust from its rocket engine is a high-energy beam of particles. The particles move at a speed of 0.60c as measured by an observer in the spaceship.



Another observer is in the inertial reference frame of the star.

For this observer

(i) calculate the length of the spaceship. *[2]*

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(ii) calculate the speed of the particles. *[2]*

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(This question continues on the following page)

(Question G1(c) continued)

(iii) state the direction of the relative motion of the particles. *[1]*

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(d) The rest mass of the spaceship is 3.0×10^3 kg. Determine the total energy, in joule, of the spaceship as measured by the observer in the inertial reference frame of the star. *[2]*

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G2. This question is about muon decay.

(a) Explain what is meant by *time dilation*. *[2]*

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(b) Discuss how observations of muons created in the upper atmosphere of Earth are used as evidence for time dilation. *[4]*

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(c) A particular muon created in the upper atmosphere of Earth has a lifetime of 2.20 μs as measured in the muon's reference frame. The speed, as measured by an observer on the ground, is 0.995c ($\gamma = 10$). Calculate the distance moved by the muon during its lifetime as measured by an observer on the ground. *[2]*

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G3. This question is about relativistic mechanics.

(a) A particle has rest mass m_0 and kinetic energy E_K. Deduce that

$$m_0c^2(\gamma - 1) = E_K$$

where $\gamma = \dfrac{1}{\sqrt{1 - \dfrac{v^2}{c^2}}}$ and c is the speed of light in a vacuum. *[2]*

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(b) A photon of energy 2.90 MeV passing close to an atom of lead becomes an electron-positron pair. The kinetic energies of the created electron and the positron are the same.

Using the expression in (a) and ignoring any recoil energy of the lead atom, determine the speed of the electron and positron. *[3]*

(rest mass of electron = rest mass of positron $= 0.510\ \text{MeV}\,\text{c}^{-2}$)

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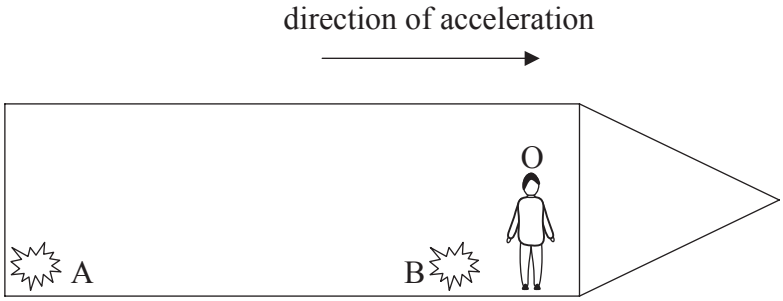
G4. This question is about general relativity.

(a) The diagram below shows a spaceship that is accelerating in the direction shown.



A and B are two identical monochromatic light sources. The observer O is standing next to the light source B and he measures the frequencies of the light emitted by the two sources.

State how the frequency of the light from source A compares to the frequency of the light from source B as measured by O. *[1]*

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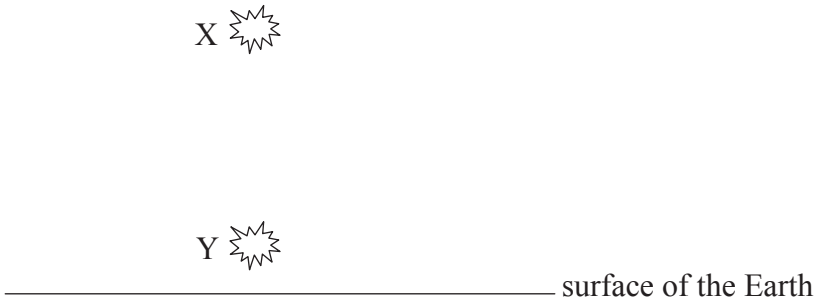
(b) The diagram below shows two identical monochromatic light sources X and Y that are at different heights above the surface of the Earth.



Explain how Einstein's principle of equivalence relates the situation in (a) to the frequency of the light emitted from the two sources as measured by an observer at X. *[2]*

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(This question continues on the following page)

(Question G4 continued)

(c) An aircraft is flying at a height of 1.40×10^4 m above the surface of Earth. A warning light on the surface of Earth emits a signal of wavelength 660 nm as measured by an observer on the surface of Earth.

Estimate the difference in **frequency** of the signal as measured by the pilot of the aircraft. *[2]*

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Option H — Optics

H1. This question is about dispersion and refractive index.

(a) State and explain what is meant by the *dispersion* of white light. *[2]*

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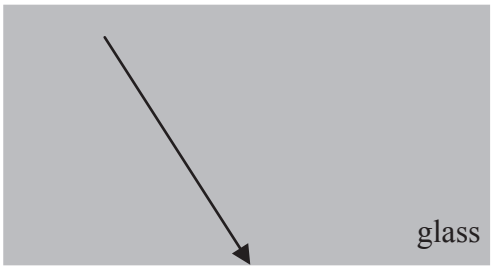
(b) A narrow beam of light is incident from glass on a boundary between glass and air as shown below.



The beam consists of a mixture of red and blue light.

(i) On the diagram above, draw labelled rays to show the path of the red and blue light in air. *[2]*

(ii) The refractive index of glass for the red light is 1.52. Calculate the maximum angle of incidence on the glass air boundary for the red light to pass into the air. *[2]*

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(iii) Explain whether the blue light would pass into the air for the angle calculated in (ii). *[2]*

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H2. This question is about an astronomical telescope.

(a) Angular magnification M of a lens or system of lenses may be defined using the expression

$$M = \frac{\theta_i}{\theta_o}.$$

Explain what is represented by the angles θ_i and θ_o. *[2]*

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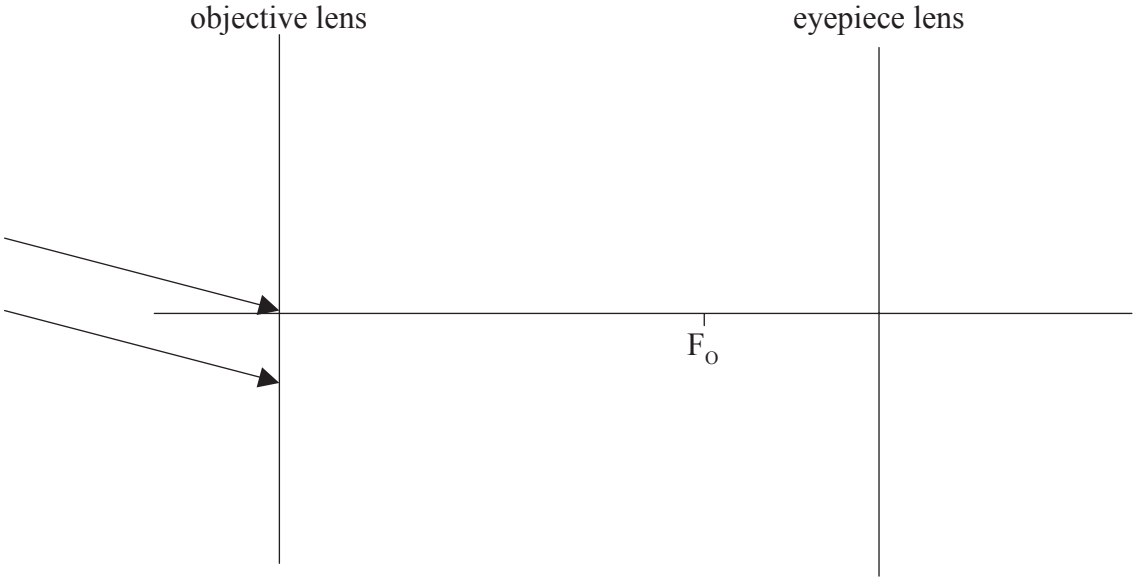
(b) The diagram below represents the objective lens and the eyepiece lens of an astronomical telescope in normal adjustment (final image formed at infinity). The point F_O is in the focal plane of the objective lens.

Two parallel rays from a distant point source are shown incident on the objective lens.



On the diagram above

(i) draw the positions of the principal foci of the eyepiece lens (label these points F_E). *[1]*

(ii) construct rays to locate the position of the final image. *[3]*

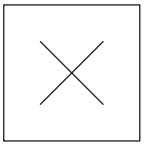
(iii) draw the position of the eye (label this with the letter E). *[1]*

(iv) label the angles θ_i and θ_o. *[1]*

(This question continues on the following page)

(Question H2 continued)

(c) A telescope is used to view a distant flat, square shaped object on which a cross has been drawn. The outline of the object is shown below.



Describe the appearance of the image of the object, including the cross, due to the lens having

(i) spherical aberration only. *[2]*

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(ii) chromatic aberration only. *[2]*

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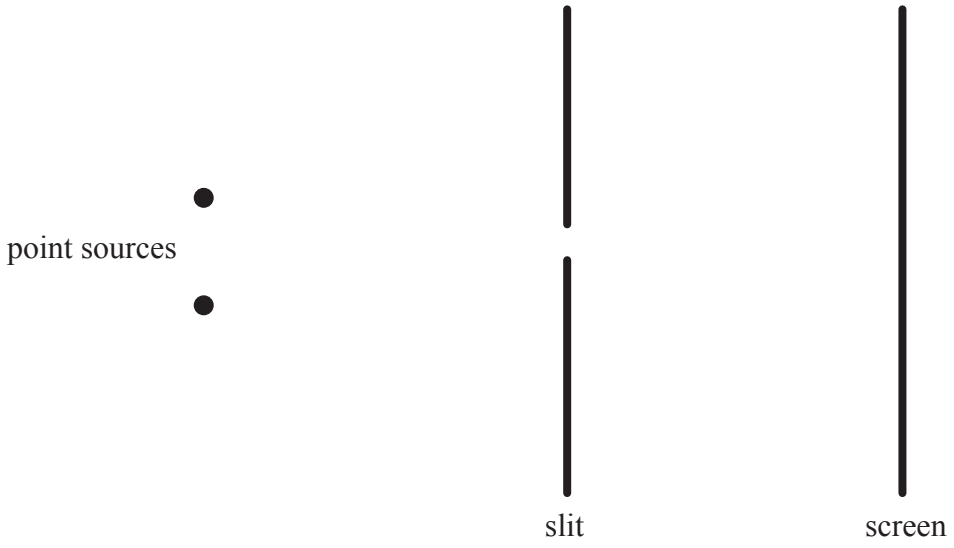
H3. This question is about resolution.

Monochromatic light from two identical point sources is incident on a narrow slit as shown below (not to scale). After passing through the slit, the light is brought to a focus on a screen.

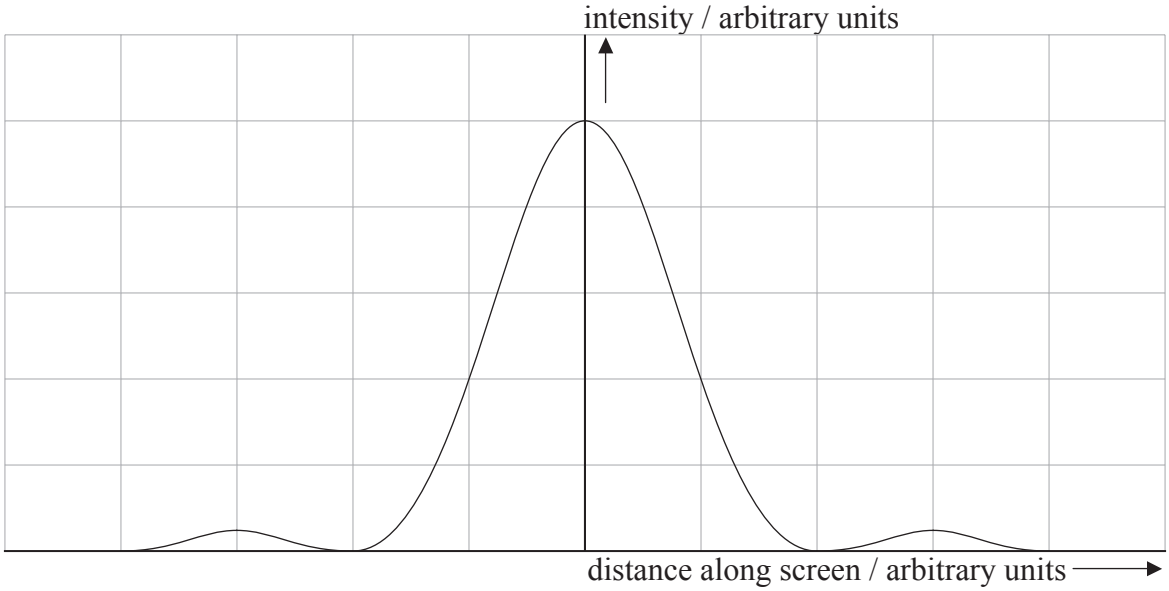


The images of the two sources on the screen are just resolved according to the Rayleigh criterion.

(This question continues on the following page)

(Question H3 continued)

The diagram below shows the intensity distribution on the screen of the light from one of the point sources.



(a) On the diagram above, draw the intensity distribution on the screen of the light due to the second source. *[2]*

(b) The planet Pluto is 4.5×10^{12} m from Earth and the diameter of Pluto is 2.3×10^{6} m. The average wavelength of the light received by the Earth from Pluto is 500 nm.

Deduce, whether the human eye should be able to see Pluto as a disc or only as a point source of light. *[3]*

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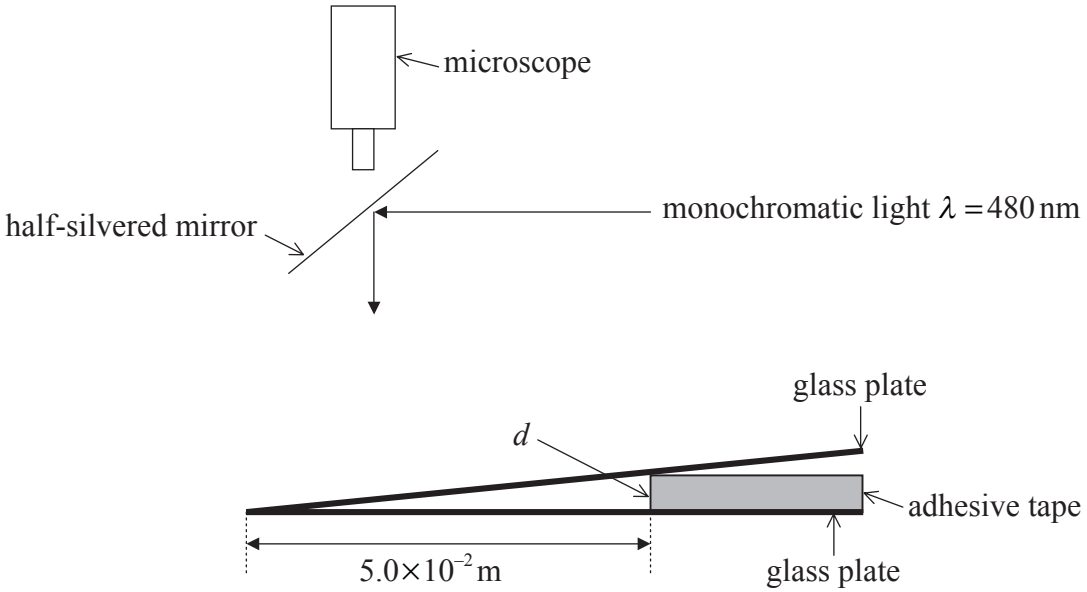
H4. This question is about a wedge film.

In an experiment to measure the thickness d of a piece of adhesive tape, the tape is used to separate two flat plates of glass as shown below. This forms a wedge shaped air film.



A beam of monochromatic light is incident on the wedge film. The light that is reflected at right angles to the wedge, is viewed using the microscope. A system of parallel fringes of equal spacing is observed in the field of view of the microscope.

(a) Outline how the fringe system is formed. *[2]*

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(b) The spacing between the fringes is $1.2\times10^{-4}\,\text{m}$. The distance from where the two plates of glass touch and the edge of the adhesive tape is $5.0\times10^{-2}\,\text{m}$. The wavelength of the light is 480 nm. Estimate the thickness d of the adhesive tape. *[3]*

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