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PHYSICS
STANDARD LEVEL
PAPER 3

Candidate session number

0	0							

Thursday 12 May 2011 (morning)

1 hour

Examination code

2	2	1	1	–	6	5	1	2

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.
- Write your answers in the boxes provided.

0136

Option A — Sight and wave phenomena

A1. This question is about standing (stationary) waves.

(a) Describe **two** ways that standing waves are different from travelling waves. *[2]*

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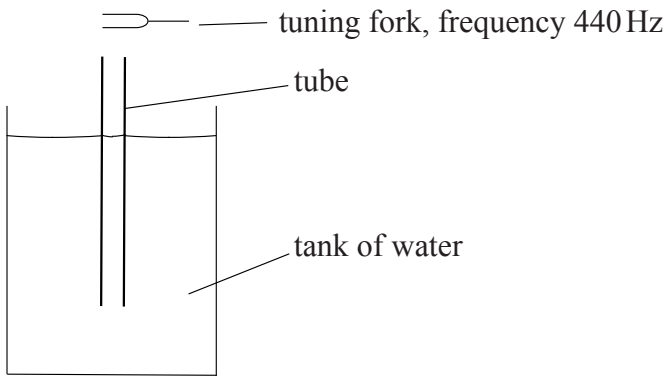
(b) An experiment is carried out to measure the speed of sound in air, using the apparatus shown below.



A tube that is open at both ends is placed vertically in a tank of water, until the top of the tube is just at the surface of the water. A tuning fork of frequency 440 Hz is sounded above the tube. The tube is slowly raised out of the water until the loudness of the sound reaches a maximum for the first time, due to the formation of a standing wave.

(i) Explain the formation of a standing wave in the tube. *[2]*

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(This question continues on the following page)

(Question A1 continued)

(ii) State the position in the tube that is always a node. *[1]*

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(iii) The tube is raised a little further. Explain why the loudness of the sound is no longer at a maximum. *[3]*

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(c) The tube is raised until the loudness of the sound reaches a maximum for a second time. Between the two positions of maximum loudness, the tube has been raised by 36.8 cm. The frequency of the sound is 440 Hz. Estimate the speed of sound in air. *[2]*

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A2. This question is about the Doppler effect.

The sound emitted by a car's horn has frequency f, as measured by the driver. An observer moves towards the stationary car at constant speed and measures the frequency of the sound to be f'.

(a) Explain, using a diagram, any difference between f' and f. *[3]*

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(b) The frequency f is $3.00\times10^{2}\,\text{Hz}$. An observer moves towards the stationary car at a constant speed of $15.0\,\text{m s}^{-1}$. Calculate the observed frequency f' of the sound. The speed of sound in air is $3.30\times10^{2}\,\text{m s}^{-1}$. *[2]*

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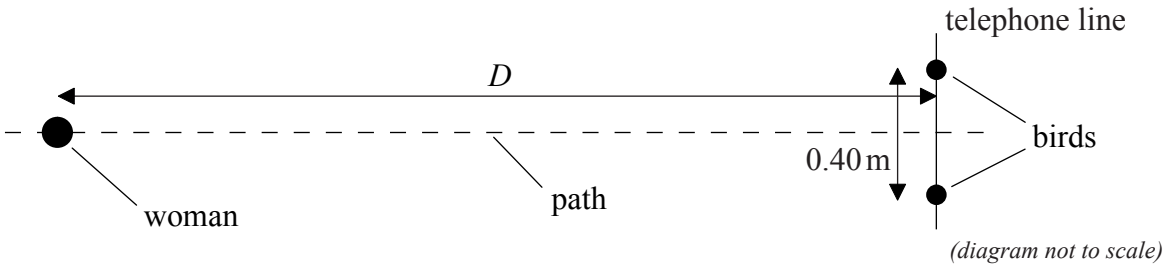
A3. This question is about optical resolution and accommodation.

A woman is walking along a straight path, which is at right angles to a telephone line, as shown in the diagram below. Two birds are perched on the line, 0.40 m apart.



(diagram not to scale)

The diameter of the pupil of the woman's eye is 2.5 mm and the average wavelength of visible light is 550 nm.

(a) Use the Rayleigh criterion to estimate the distance D at which the woman will just be able to see two separate birds. *[3]*

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(b) The woman looks down at her watch and is able to focus on it clearly. Explain how her eyes are able to focus on near objects as well as far objects. *[2]*

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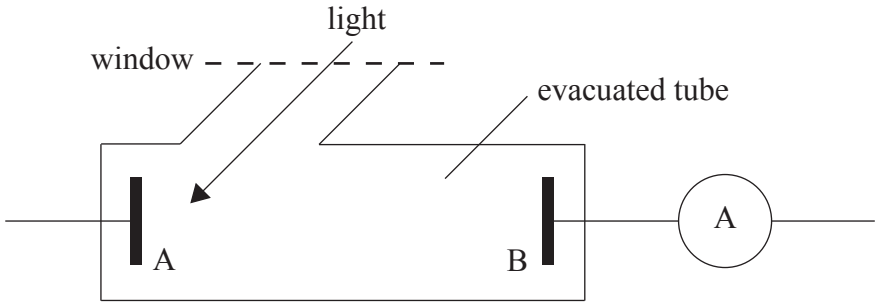
Answers written on this page
will not be marked.

Option B — Quantum physics and nuclear physics

B1. This question is about the photoelectric effect.

In an experiment to investigate the photoelectric effect, light of frequency f is incident on the metal surface A, shown in the diagram below. A potential difference is applied between A and B. The photoelectric current is measured by a sensitive ammeter. (Note: the complete electrical circuit is not shown.)



When the frequency of the light is reduced to a certain value, the current measured by the ammeter becomes zero. Explain how Einstein's photoelectric theory accounts for this observation. *[4]*

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B2. This question is about atomic spectra.

Diagram 1 shows some of the energy levels of the hydrogen atom. Diagram 2 is a representation of part of the emission spectrum of atomic hydrogen. The lines shown represent transitions involving the –3.40 eV level.

Diagram 1

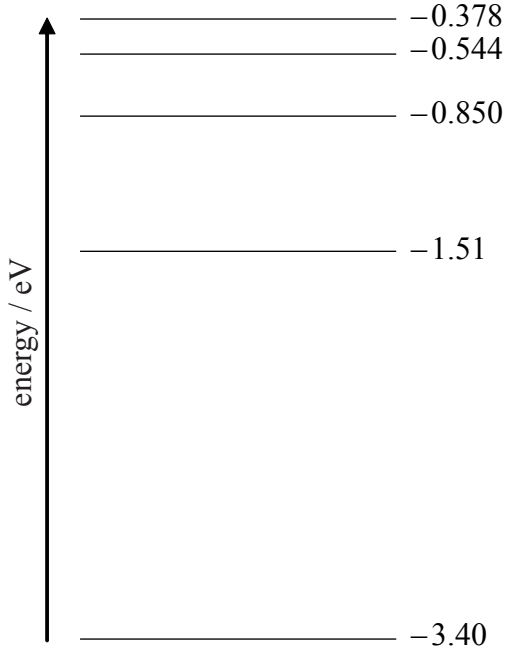
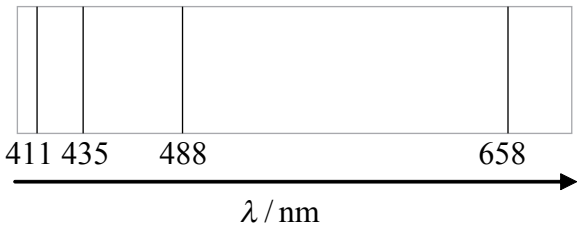


Diagram 2



(a) Deduce that the energy of a photon of wavelength 658 nm is 1.89 eV. *[3]*

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(This question continues on the following page)

(Question B2 continued)

(b) (i) On **diagram 1**, draw an arrow to show the electron transition between energy levels that gives rise to the emission of a photon of wavelength 658 nm. Label this arrow with the letter A. *[1]*

(ii) On **diagram 1**, draw arrows to show the electron transitions between energy levels that give rise to the emission of photons of wavelengths 488 nm, 435 nm and 411 nm. Label these arrows with the letters B, C and D. *[1]*

(c) Explain why the lines in the emission spectrum of atomic hydrogen, shown in **diagram 2**, become closer together as the wavelength of the emitted photons decreases. *[3]*

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B3. This question is about radioactive decay.

Iodine-124 (I-124) is an unstable radioisotope with proton number 53. It undergoes beta plus decay to form an isotope of tellurium (Te).

(a) State the reaction for the decay of the I-124 nuclide. *[2]*

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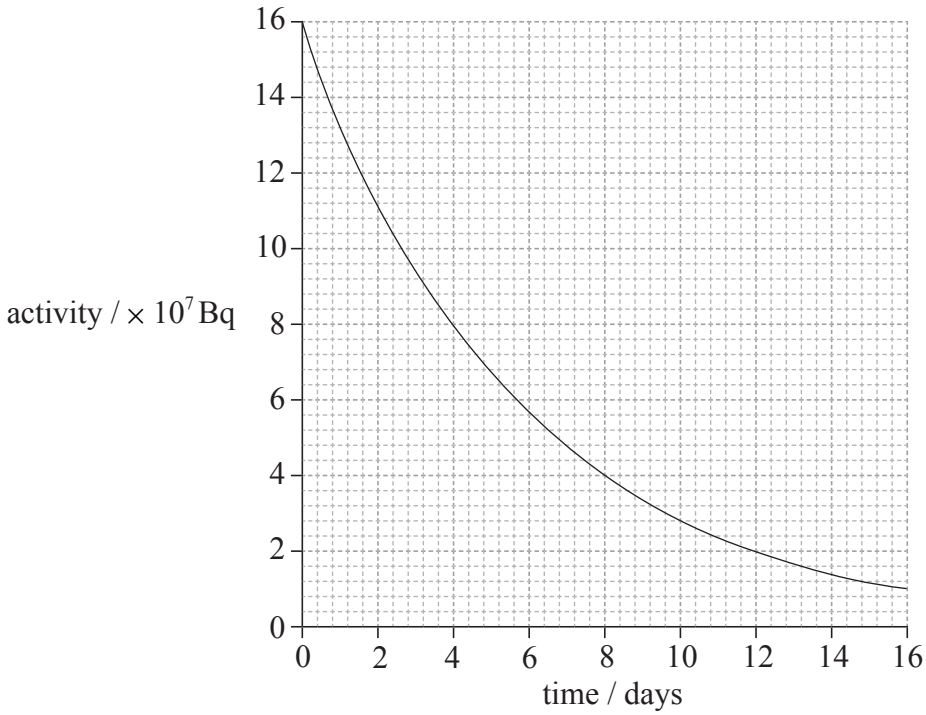
(b) The graph below shows how the activity of a sample of iodine-124 changes with time.



(This question continues on the following page)

(Question B3 continued)

(i) State the half-life of iodine-124. *[1]*

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(ii) Calculate the activity of the sample at 21 days. *[3]*

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(iii) A sample of an unknown radioisotope has a half-life twice that of iodine-124 and the same initial activity as the sample of iodine-124. On the axes opposite, draw a graph to show how the activity of the sample would change with time. Label this graph X. *[1]*

(iv) A second sample of iodine-124 has half the initial activity as the original sample of iodine-124. On the axes opposite, draw a graph to show how the activity of this sample would change with time. Label this graph Y. *[1]*

Option C— Digital technology

C1. This question is about analogue and digital storage.

As part of a physics lesson, Isobel and Claire each make an audio recording of their teacher. They then compare the quality of their recordings. Isobel's recording is in analogue format whereas Claire's recording is digital and stored on a CD.

(a) State **one** possible analogue method of storage used by Isobel. *[1]*

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(b) The first time the recordings are played, their qualities are identical. Outline whether the quality of each recording is expected to remain the same after many uses. *[2]*

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(c) Use the following information to determine the number of bits used in Claire's digital recording. *[2]*

Total time of recording	=	30 minutes
Sampling frequency	=	40 kHz
Format of recording	=	Stereo (2 channels)
Number of bits per sample	=	16

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C2. This question is about charge-coupled devices (CCDs).

An image of the surface of the Earth is recorded by a digital camera from an aeroplane. Each image covers 144 km^2 of the Earth's surface and is recorded by a square CCD of area 36 cm^2.

(a) Calculate the magnification of the system. *[2]*

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(b) The CCD contains 1.0×10^8 pixels. Deduce the minimum distance between two points on Earth that can be resolved by this camera. *[2]*

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(c) It is proposed to improve the quantum efficiency of the CCD. State the effect, if any, on the resolution of the system. *[1]*

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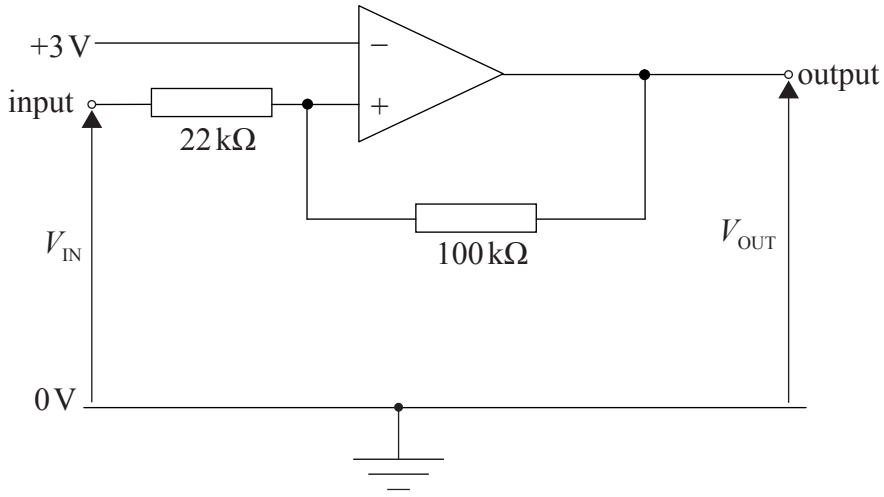
C3. This question is about a Schmitt trigger.

The diagram below shows a Schmitt trigger circuit based on an operational amplifier (op-amp).



The output of this Schmitt trigger is positive saturation (+13 V) or negative saturation (–13 V).

(a) State **two** properties of an ideal op-amp. *[2]*

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(b) Determine the input value that will cause the output to switch from –13 V to +13 V. *[3]*

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(Question C3 continued)

(c) Explain how a Schmitt trigger can be used to reshape a digital pulse. *[3]*

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C4. This question is about a mobile phone network.

Erin is a passenger on a train making a call to a standard fixed telephone line ("landline") from her mobile phone. The train moves Erin between adjacent communication cells. Outline the changes, if any, that take place in the

(a) cellular exchange. *[1]*

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(b) public switched telephone network (PSTN). *[1]*

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Option D — Relativity and particle physics

D1. This question is about length contraction and simultaneity.

(a) Define *proper length.* *[1]*

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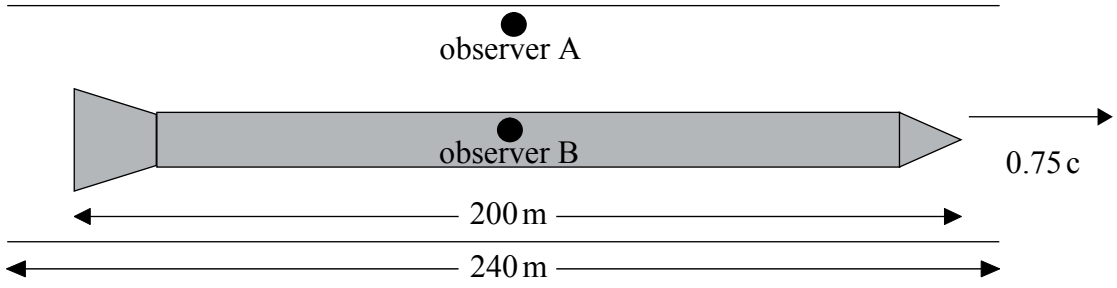
(b) A spaceship is travelling to the right at speed 0.75 c, through a tunnel which is open at both ends. Observer A is standing at the centre of one side of the tunnel. Observer A, for whom the tunnel is at rest, measures the length of the tunnel to be 240 m and the length of the spaceship to be 200 m. The diagram below shows this situation from the perspective of observer A.



Observer B, for whom the spaceship is stationary, is standing at the centre of the spaceship.

(i) Calculate the Lorentz factor, γ, for this situation. *[1]*

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(ii) Calculate the length of the tunnel according to observer B. *[1]*

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(This question continues on the following page)

(Question D1 continued)

(iii) Calculate the length of the spaceship according to observer B. *[1]*

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(iv) According to observer A, the spaceship is completely inside the tunnel for a short time. State and explain whether or not, according to observer B, the spaceship is ever completely inside the tunnel. *[2]*

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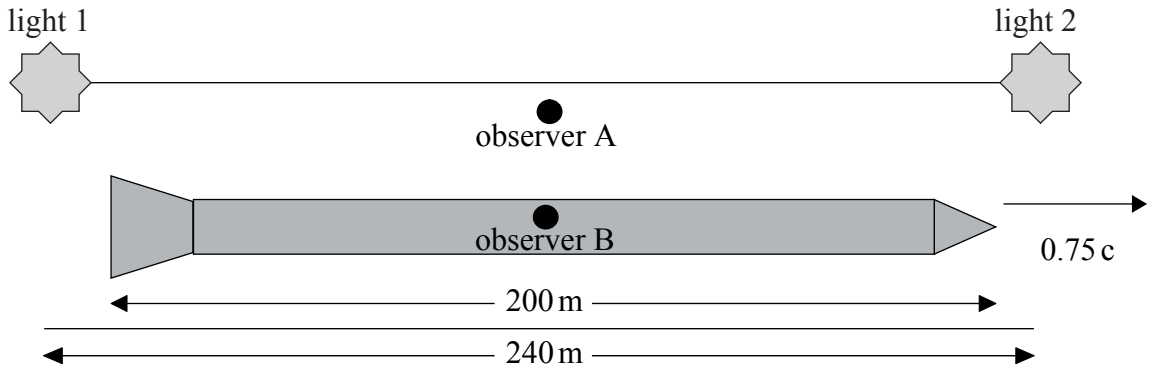
(Question D1 continued)

(c) Two sources of light are located at each end of the tunnel. The diagram below shows this situation from the perspective of observer A.



According to observer A, at the instant when observer B passes observer A, the two sources of light emit a flash. Observer A sees the two flashes simultaneously. Discuss whether or not observer B sees the two flashes simultaneously. *[4]*

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D2. This question is about mesons.

(a) State what is meant by an exchange particle. *[1]*

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(b) In 1935, the physicist Hideki Yukawa predicted that the strong interaction between nucleons was mediated by particles called mesons. Given that the range of the strong interaction is approximately $1.5\times10^{-15}\,\text{m}$, calculate a possible value for the rest mass of a meson. *[2]*

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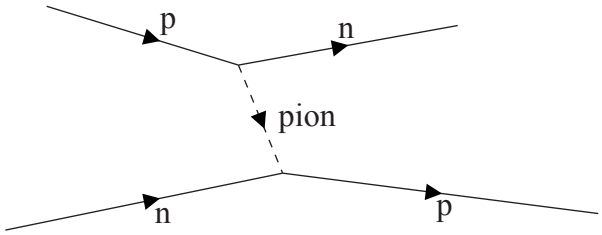
(This question continues on the following page)

(Question D2 continued)

(c) A meson called the pion was detected in cosmic ray reactions in 1947 by Powell and Occhialini. The pion comes in three possible charge states: π^+, π^- and π^0. The Feynman diagram below represents a possible reaction in which a pion participates.



State and explain whether the meson produced is a π^+, π^- **or** a π^0. *[2]*

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(d) State the possible spin numbers of mesons and explain your answer. *[3]*

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(This question continues on the following page)

(Question D2 continued)

(e) Explain why, according to the quark model, it is not possible for a particle to consist of two up quarks only. *[2]*

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Answers written on this page
will not be marked.

Option E — Astrophysics

E1. This question is about some of the planets in the solar system.

Four of the planets in the solar system are Mars, Venus, Jupiter and Neptune.

(a) List these planets in order of increasing distance from the Sun. *[2]*

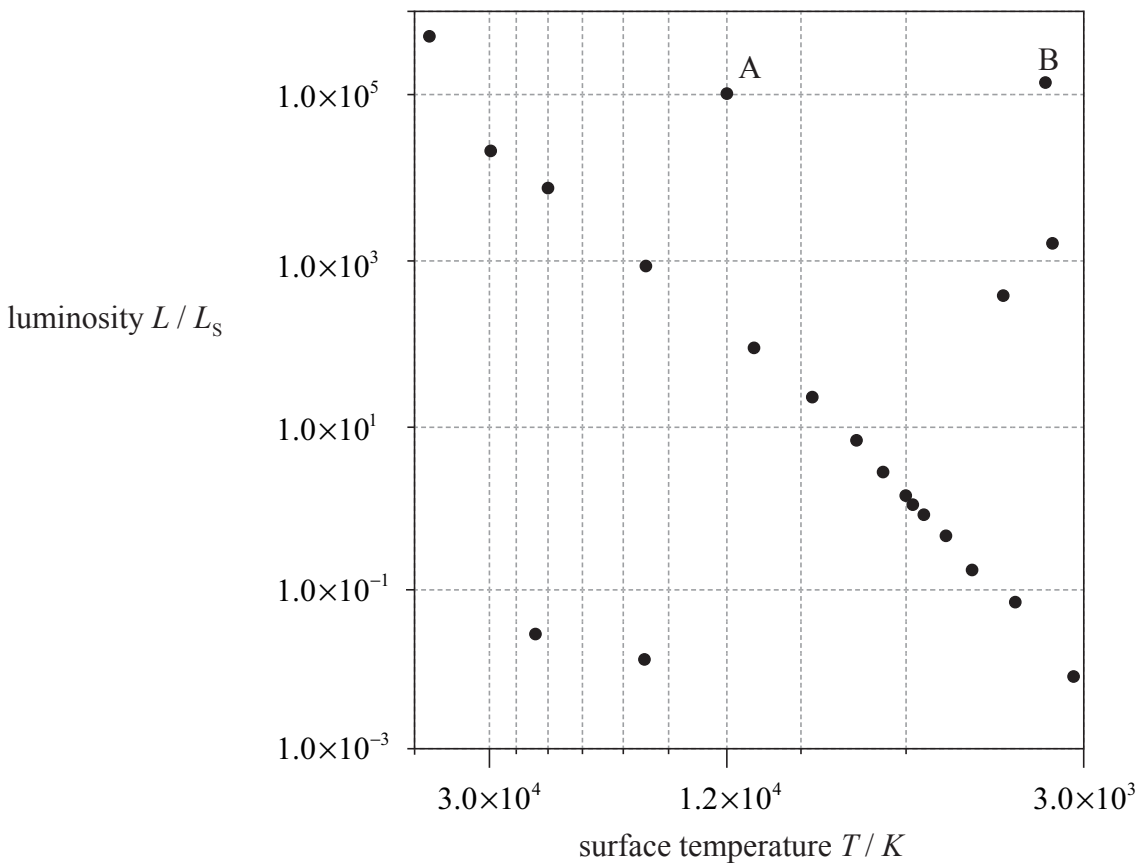
Nearest the Sun	
↓	
Furthest from the Sun	

(b) List these planets in order of decreasing diameter. *[2]*

Largest diameter	
↓	
Smallest diameter	

E2. This question is about the Hertzsprung–Russell (HR) diagram and using it to determine some properties of stars.

The diagram below shows the grid of a HR diagram, on which the positions of selected stars are shown. (L_S = luminosity of the Sun.)



(a) (i) Draw a circle around the stars that are red giants. Label this circle R. *[1]*

(ii) Draw a circle around the stars that are white dwarfs. Label this circle W. *[1]*

(iii) Draw a line through the stars that are main sequence stars. *[1]*

(This question continues on the following page)

(Question E2 continued)

(b) Explain, without doing any calculation, how astronomers can deduce that star B has a larger diameter than star A. *[3]*

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(c) Using the following data and information from the HR diagram, show that star A is at a distance of about 800 pc from Earth. *[4]*

Apparent brightness of the Sun $= 1.4 \times 10^{3}\ \text{Wm}^{-2}$
Apparent brightness of star A $= 4.9 \times 10^{-9}\ \text{Wm}^{-2}$
Mean distance of Sun from Earth $= 1.0\ \text{AU}$
$1\ \text{pc} = 2.1 \times 10^{5}\ \text{AU}$

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

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E3. This question is about cosmology.

(a) State how the observed red-shift of many galaxies is explained. *[1]*

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(b) Explain how the cosmic microwave background (CMB) radiation is consistent with the Big Bang model. *[2]*

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(c) Calculate the temperature of the universe when the peak wavelength of the CMB was equal to the wavelength of red light (7.0×10^{-7} m). *[2]*

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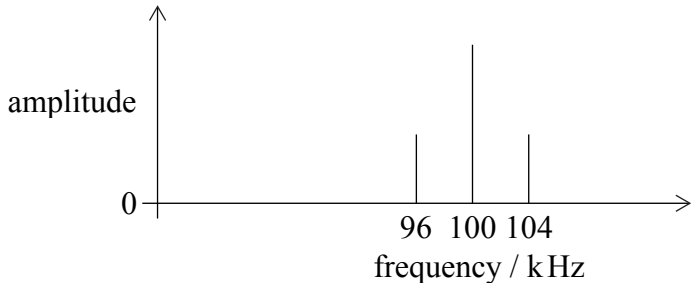
Option F — Communications

F1. This question is about modulation.

In order to test a temporary radio communication link, an audio signal is broadcast using amplitude modulation (AM). The power spectrum of the resulting carrier wave is shown below.



(a) Use the information in the power spectrum to determine the

(i) frequency of the carrier wave. *[1]*

. . . . . .

(ii) frequency of the audio signal. *[1]*

. . . . . .

(iii) bandwidth of this signal. *[1]*

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(This question continues on the following page)

(Question F1 continued)

(b) (i) Distinguish between AM and frequency modulation (FM). *[2]*

AM: . . . . . .
. . . . . .

FM: . . . . . .
. . . . . .

(ii) Outline **one** advantage and **one** disadvantage of using FM as opposed to AM for the transmission. *[2]*

Advantage: . . . . . .
. . . . . .

Disadvantage: . . . . . .
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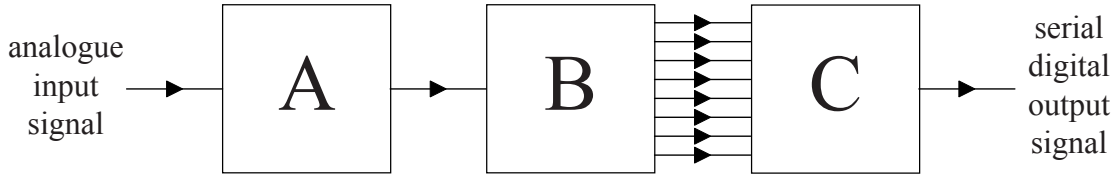
F2. This question is about data transmission systems.

The block diagram below represents an electronic system, S_1, which converts an analogue input signal into a serial digital output signal ready for transmission. It involves three separate system blocks labelled A, B and C.

System S_1



(a) State whether the signal between block A and block B is analogue, digital or multiplexed. *[1]*

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(b) State the function of system block A. *[1]*

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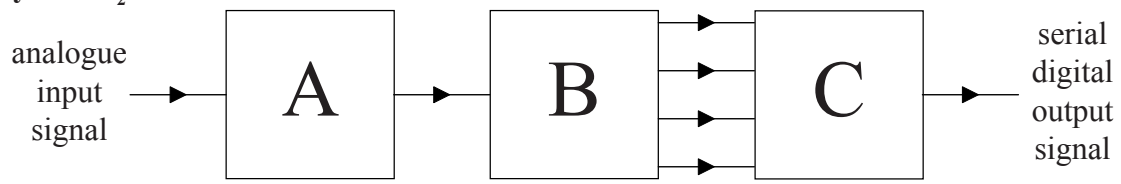
(This question continues on the following page)

(Question F2 continued)

(c) A similar system, S_2, is based on the same system blocks as S_1, but has fewer signal lines between block B and block C, as shown below.

System S_2



Explain what differences, if any, there are between S_1 and S_2 with respect to the maximum quality of the reproduction of the analogue signal after transmission. *[2]*

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(d) The serial digital output signal is transmitted using an optical fibre link. The attenuation per unit length of the optical fibre is $-4\,\text{dB}\,\text{km}^{-1}$.

(i) Define *attenuation*. *[1]*

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(ii) The input power to the fibre optic cable is 100 mW and the output power at the end of the cable is 1 mW. Determine the length of the cable. *[2]*

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(This question continues on the following page)

(Question F2 continued)

(iii) State **two** processes that must take place in order for this digital signal to be transmitted over a very long distance. *[2]*

1. . . . . .

2. . . . . .

F3. This question is about satellites.

A geostationary satellite is used by one country to broadcast information to a different country.

(a) State which part of the electromagnetic spectrum is used for this type of communication. *[1]*

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(b) Explain **two** disadvantages of using a polar satellite for this type of communication, when compared with using a geostationary satellite. *[2]*

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(c) Outline **one** possible ethical issue associated with this broadcast. *[1]*

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Option G — Electromagnetic waves

G1. This question is about dispersion.

(a) State an approximate value for the wavelength of visible light. *[1]*

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(b) Describe what is meant by dispersion. *[2]*

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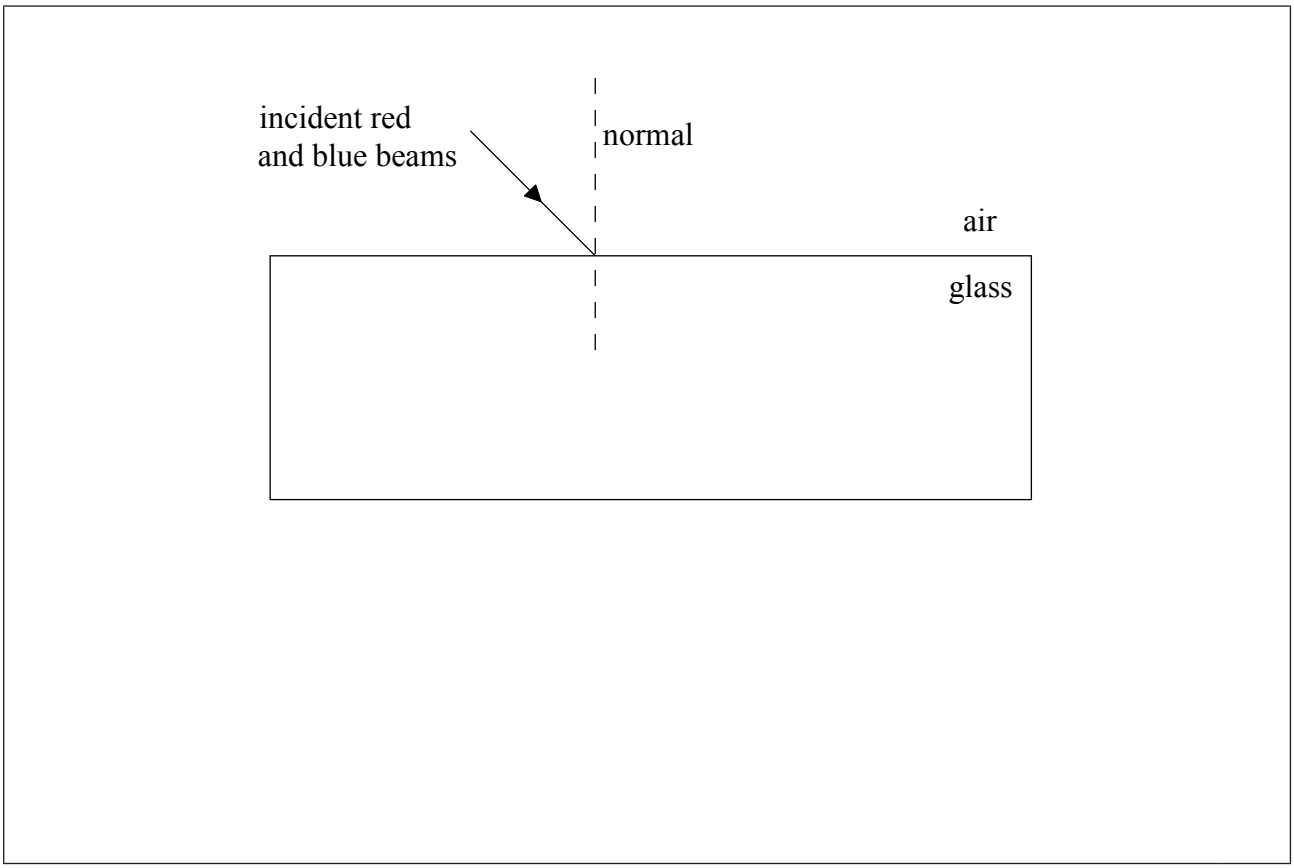
(Question G1 continued)

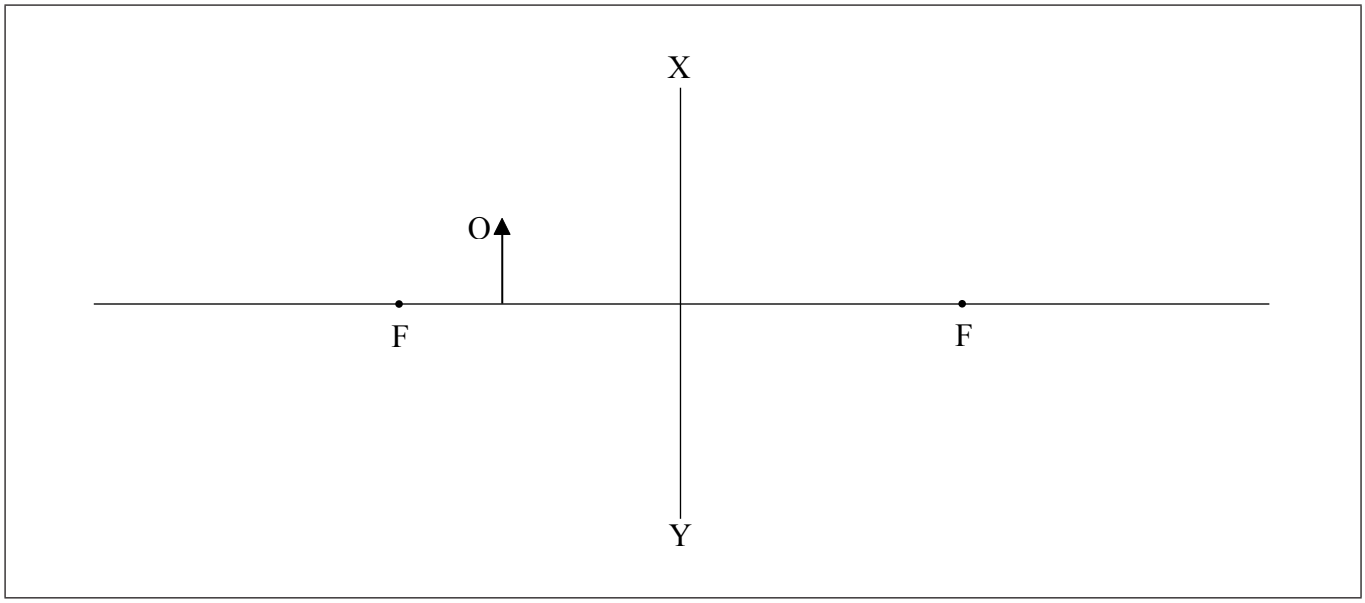
(c) A narrow beam, consisting of a mixture of red and blue light, is incident upon a rectangular glass block. The normal to the incident surface is shown.



On the diagram above, draw labelled lines to show the paths of the red and blue beams, as they pass through the glass block and out to the air on the other side. *[2]*

G2. This question is about a convex lens.

The diagram below, drawn to scale, shows a small object O placed in front of a thin convex (converging) lens. The focal points of the lens are shown, labelled F. The lens is represented by the straight line XY.



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

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(ii) On the diagram above, construct the paths of two rays in order to locate the position of the image formed by the lens. Label the image I. *[3]*

(iii) Explain whether the image is real **or** virtual. *[1]*

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(This question continues on the following page)

(Question G2 continued)

(b) A converging lens, of focal length 5.0 cm, is used as a simple magnifying glass to view an object of length 0.80 cm. The observer's eye is very close to the lens. The image is formed at the near point (25 cm).

(i) Determine the distance of the object from the lens. *[2]*

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(ii) Determine the length of the image. *[2]*

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G3. This question is about using a diffraction grating to view the emission spectrum of sodium.

Light from a sodium discharge tube is incident normally upon a diffraction grating having 8.00×10^5 lines per metre. The spectrum contains a double yellow line of wavelengths 589 nm and 590 nm.

(a) Determine the angular separation of the two lines when viewed in the second order spectrum. *[4]*

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(b) State why it is more difficult to observe the double yellow line when viewed in the first order spectrum. *[1]*

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