Diploma Programme
Programme du diplôme
Programa del Diploma

Physics
Standard level
Paper 3

Tuesday 10 November 2015 (afternoon)

Candidate session number

1 hour

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.
- A calculator is required for this paper.
- A clean copy of the **physics data booklet** is required for this paper.
- The maximum mark for this examination paper is **[40 marks]**.

Option	Questions
Option A — Sight and wave phenomena	1 – 4
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39 pages

8815 – 6506

Option A — Sight and wave phenomena

1. This question is about the eye.

(a) Explain, with reference to spectral response, why the eye has poor colour sensitivity under scotopic vision. [3]

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(b) Outline how the distribution of retinal cells in the eye accounts for differences in perception. [2]

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(Option A continues on the following page)

(Option A continued)

2. This question is about sound waves.

A whistle on a steam train consists of a pipe that is open at one end and closed at the other. The sounding length of the whistle is 0.27 m and the steam pressure in the whistle is so great that the third harmonic of the pipe is sounding. The speed of sound in air is 340 m s^{-1}.

(a) (i) Show that there must be a node at a distance of 0.18 m from the closed end of the pipe. [1]

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(ii) Calculate the frequency of the whistle sound. [2]

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(b) The train is moving directly away from a stationary observer at a speed of 22 m s^{-1} while the whistle is sounding. Calculate the frequency heard by the observer. [2]

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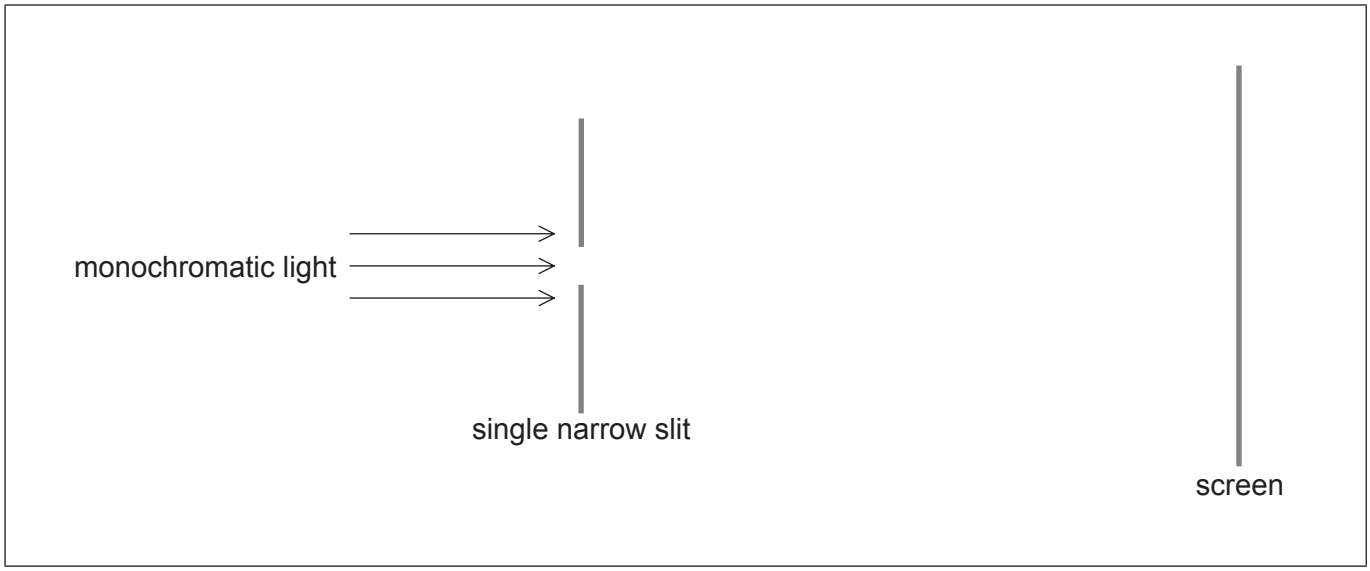
(Option A continues on the following page)

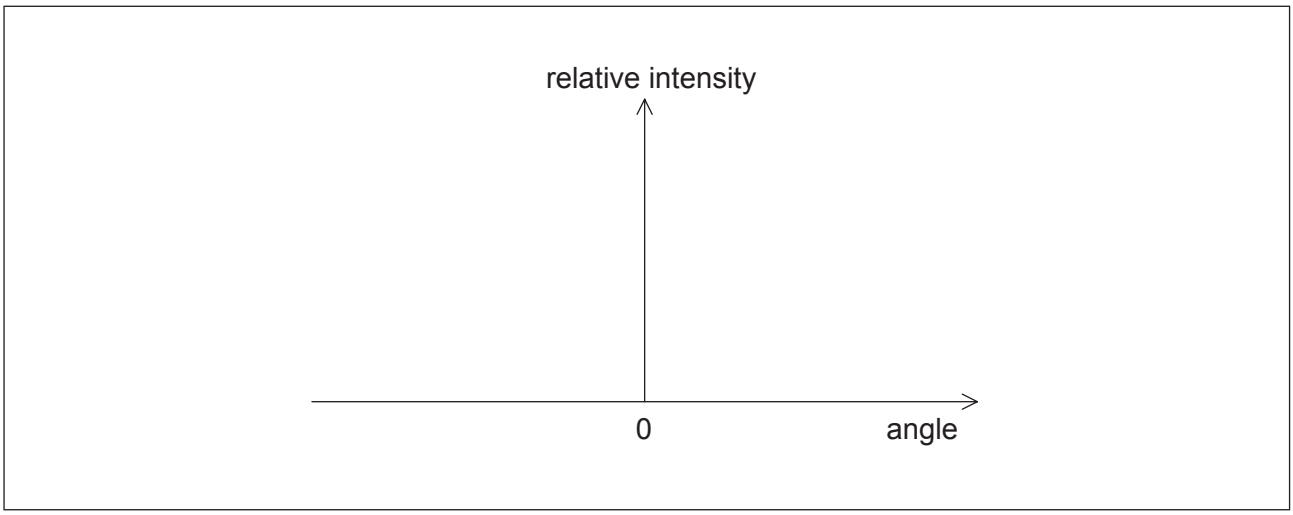
(Option A continued)

3. This question is about diffraction and resolution.

Monochromatic light is incident normally on a single narrow slit and gives rise to a diffraction pattern on a screen.



(a) Sketch, for the diffraction pattern produced, a graph showing the variation of the relative intensity of the light with the angle measured from the centre of the slit. [2]



(Option A continues on the following page)

(Option A, question 3 continued)

(b) The single narrow slit is replaced by a double narrow slit. Explain, with reference to your answer to (a), how the Rayleigh criterion applies to the diffraction patterns produced by the light emerging from the two slits. [3]

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(c) Two lamps emit light of wavelength 620 nm. The lights are observed through a circular aperture of diameter 1.5 mm from a distance of 850 m. Calculate the minimum distance between the lamps so that they are resolved. [2]

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4. This question is about polarization.

Mathematical calculators often use a liquid-crystal display (LCD). Outline how you would demonstrate that the display emits plane polarized light. [3]

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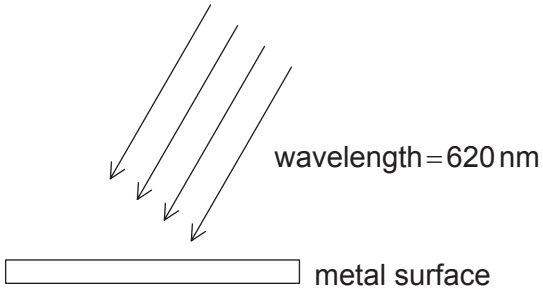
End of Option A

Option B — Quantum physics and nuclear physics

5. This question is about the photoelectric effect.

When light is incident on a clean metal surface, electrons can be emitted through the photoelectric effect.



(a) Outline how the Einstein model is used to explain the photoelectric effect. [2]

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(b) State why, although the incident light is monochromatic, the energies of the emitted electrons vary. [1]

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(Option B continues on the following page)

(Option B, question 5 continued)

(c) Explain why no electrons are emitted if the frequency of the incident light is less than a certain value, no matter how intense the light. [2]

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(d) For monochromatic light of wavelength 620 nm a stopping potential of 1.75 V is required. Determine the minimum energy required to emit an electron from the metal surface. [2]

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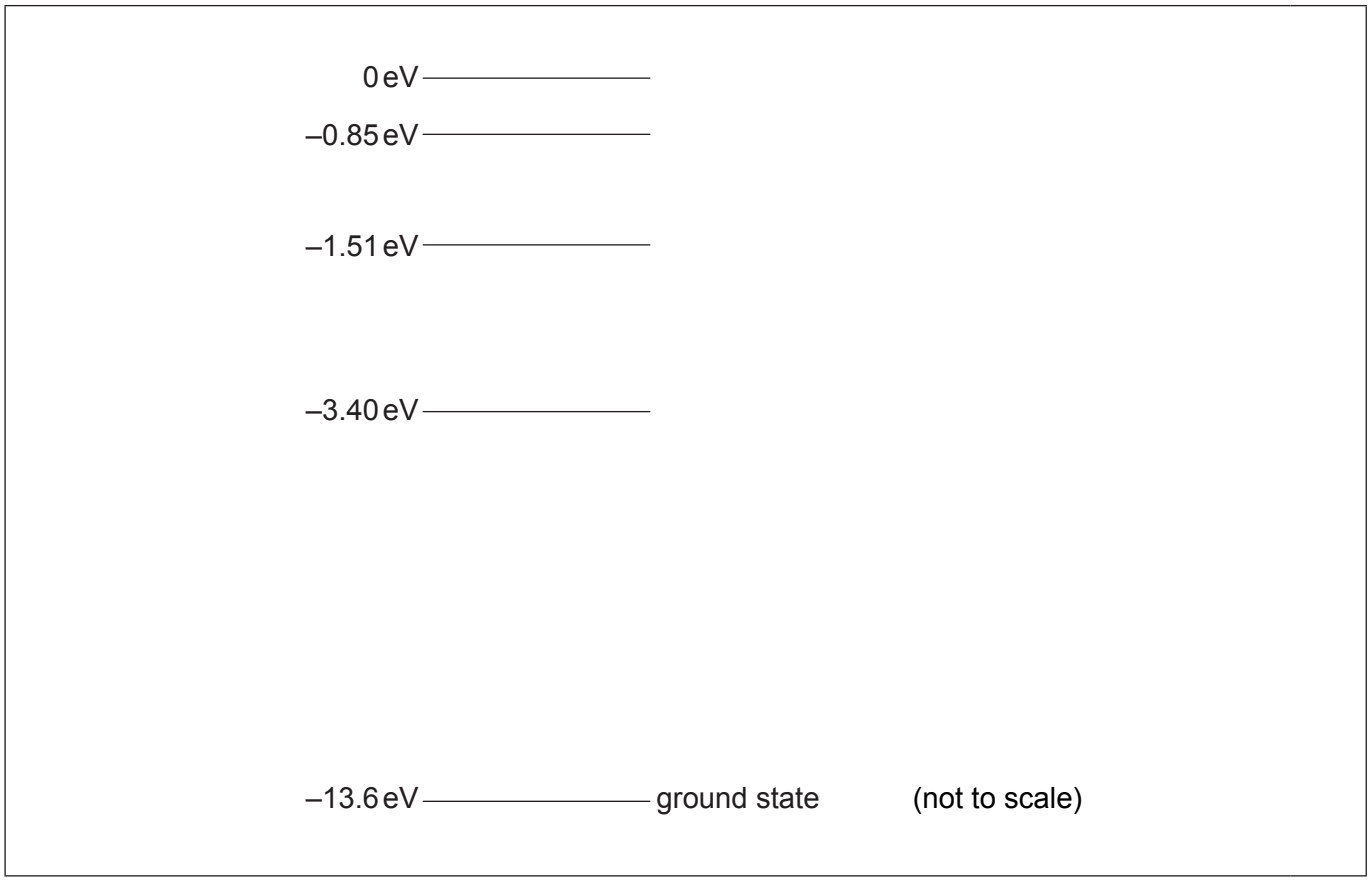
(Option B continues on the following page)

(Option B continued)

6. This question is about energy level transitions.

Some of the electron energy levels for a hydrogen atom are shown.



(a) A hydrogen atom is excited to the –1.51 eV level.

(i) On the diagram, label using arrows all the possible transitions that might occur as the hydrogen atom returns to the ground state. [1]

(ii) State the energy in eV of the maximum wavelength photon emitted as the hydrogen atom returns to the ground state. [1]

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(Option B continues on the following page)

(Option B, question 6 continued)

(b) Monochromatic radiation is incident on gaseous hydrogen. All the hydrogen atoms are in the ground state. Describe what could happen to the radiation and to the hydrogen atoms if the incident photon energy is equal to

(i) 10.2 eV. [2]

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(ii) 9.0 eV. [1]

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(Option B continues on the following page)

(Option B continued)

7. This question is about radioactive decay.

Meteorites contain a small proportion of radioactive aluminium-26 $\left({}^{26}_{13}\text{Al}\right)$ in the rock. The amount of ${}^{26}_{13}\text{Al}$ is constant while the meteorite is in space due to bombardment with cosmic rays.

(a) Aluminium-26 decays into an isotope of magnesium (Mg) by β^+ decay.

$$ {}^{26}_{13}\text{Al} \rightarrow {}^{X}_{Y}\text{Mg} + \beta^+ + Z $$

Identify X, Y and Z in this nuclear decay process. [2]

X: . . . . . .

Y: . . . . . .

Z: . . . . . .

(b) Explain why the beta particles emitted from the aluminium-26 have a continuous range of energies. [2]

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(Option B continues on the following page)

(Option B, question 7 continued)

(c) After reaching Earth, the number of radioactive decays per unit time in a meteorite sample begins to diminish with time. The half-life of aluminium-26 is 7.2×10^5 years.

(i) State what is meant by half-life. [1]

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(ii) A meteorite which has just fallen to Earth has an activity of 36.8 Bq. A second meteorite of the same mass, which arrived some time ago, has an activity of 11.2 Bq. Determine, in years, the time since the second meteorite arrived on Earth. [3]

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End of Option B

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will not be marked.

Option C — Digital technology

8. The question is about data storage capacity.

(a) Printed text is being converted to a digital form so that it is more portable. State **one** other reason for the conversion of text into a digital format. [1]

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(b) A publisher is converting all its books into digital form. Estimate how many pages of text can be stored on a CD that has a storage capacity of 700 M byte. Each letter or symbol on the page is represented by 16 bits. On average, there are 500 words per page. [3]

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(Option C continues on the following page)

(Option C continued)

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

(a) Define *capacitance*. [1]

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(b) Photons of a certain frequency are incident on the surface of a CCD.

The following data are available.

Intensity of the photons incident on the CCD	$= 1.6\,\text{mW}\,\text{m}^{-2}$
Area of the pixel	$= 2.1 \times 10^{-12}\,\text{m}^2$
Energy carried by a photon	$= 4.8 \times 10^{-19}\,\text{J}$
Quantum efficiency of CCD	$= 60\,\%$
Capacitance of a pixel	$= 170\,\text{pF}$

Show that the potential difference across the pixel will be $0.6\,\mu\text{V}$ after it has been exposed to light for 0.15 s. [4]

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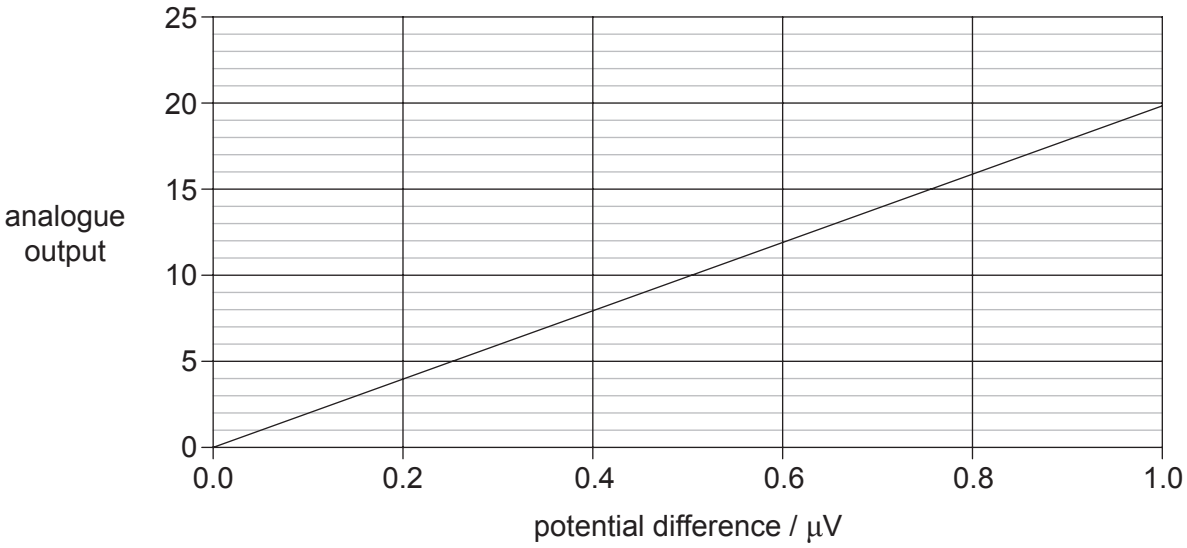
(Option C continues on the following page)

(Option C, question 9 continued)

(c) The graph shows how the analogue output signal from the pixel varies with the potential difference that is developed across the pixel. This analogue signal is then converted into an equivalent 4-bit digital signal.



Using your answer to (b) and the graph, state the 4-bit digital output from this pixel. [1]

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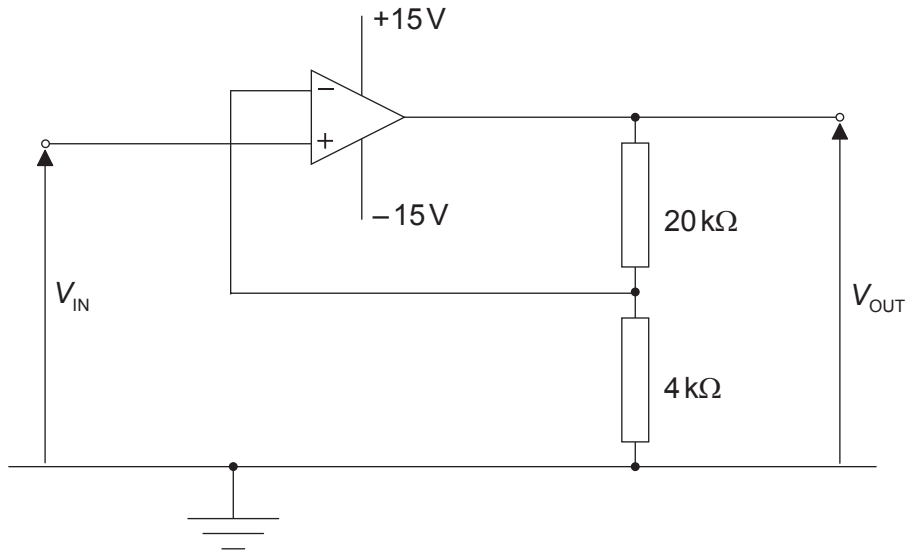
(Option C continues on the following page)

(Option C continued)

10. This question is about an amplifier circuit.

The diagram shows an amplifier circuit incorporating an ideal operational amplifier (op-amp).



(a) (i) Calculate the gain of the circuit. [2]

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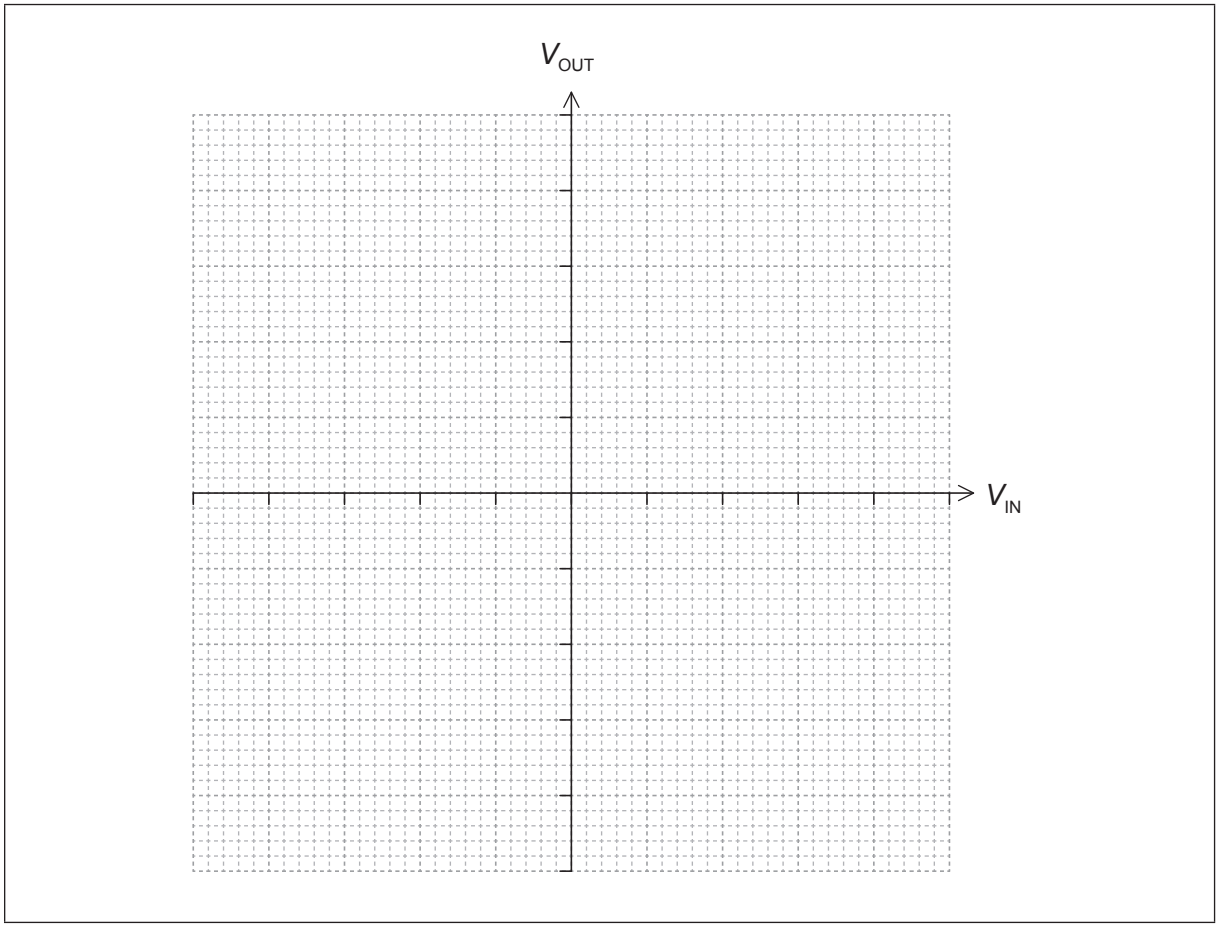
(Option C continues on the following page)

(Option C, question 10 continued)

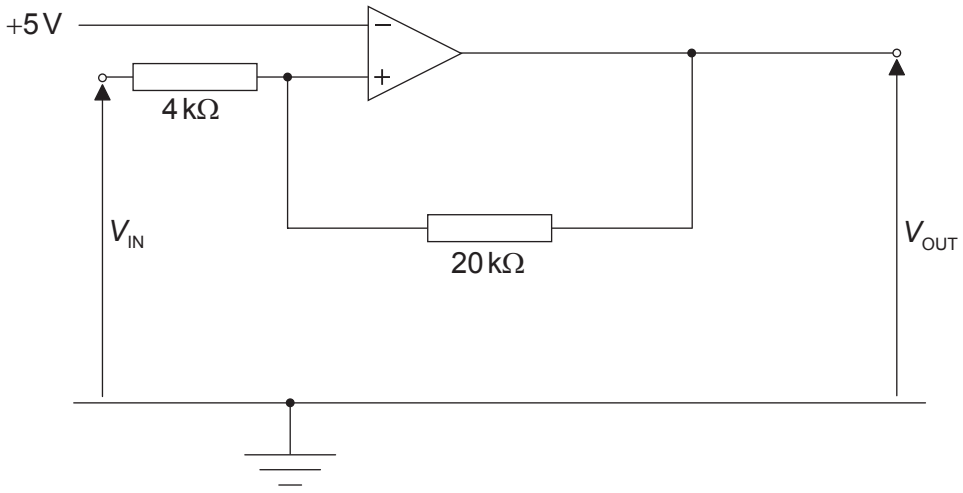
(ii) Using the axis, sketch the variation with input voltage V_{IN} of the output voltage V_{OUT}. [3]



(Option C continues on the following page)

(Option C, question 10 continued)

(b) The circuit is now rearranged to function as a Schmitt trigger.



The output of the Schmitt trigger is positive saturation (+15 V) or negative saturation (–15 V). Calculate the input value that will cause the output to switch from –15 V to +15 V. [3]

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11. This question is about mobile phones.

The number of mobile phones has grown rapidly in recent years. Discuss environmental issues associated with this rapid increase. [2]

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End of Option C

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Option D — Relativity and particle physics

12. This question is about relativistic kinematics.

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

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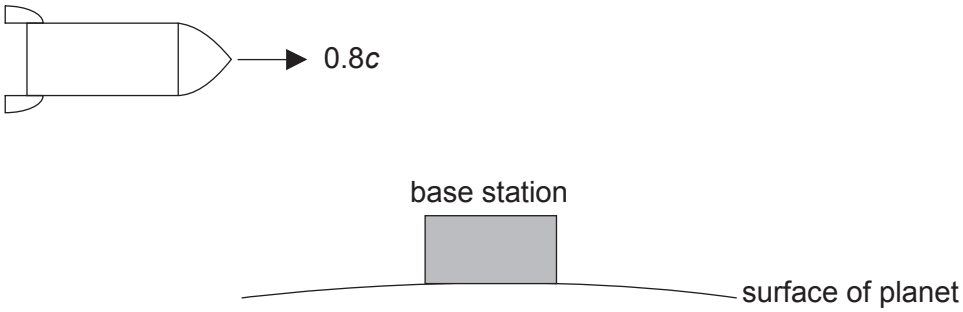
(b) A spacecraft is flying in a straight line above a base station at a speed of 0.8*c*.



Suzanne is inside the spacecraft and Juan is on the base station.

(i) A light on the base station flashes regularly. According to Suzanne, the light flashes every 3 seconds. Calculate how often the light flashes according to Juan. [2]

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(Option D continues on the following page)

(Option D, question 12 continued)

(ii) While moving away from the base station, Suzanne observes another spacecraft travelling towards her at a speed of 0.8*c*. Using Galilean transformations, calculate the relative speed of the two spacecraft. [1]

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(iii) Using the postulates of special relativity, state and explain why Galilean transformations cannot be used in this case to find the relative speeds of the two spacecraft. [2]

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(iv) Using relativistic kinematics, the relative speeds of the two spacecraft is shown to be 0.976*c*. Suzanne measures the other spacecraft to have a length of 8.00 m. Calculate the proper length of the other spacecraft. [2]

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(c) Suzanne's spacecraft is on a journey to a star. According to Juan, the distance from the base station to the star is 11.4 ly. Show that Suzanne measures the time taken for her to travel from the base station to the star to be about 9 years. [2]

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(Option D continues on the following page)

(Option D continued)

13. This question is about interactions and quarks.

(a) A lambda baryon Λ^0 is composed of the three quarks uds. Show that the charge is 0 and the strangeness is –1. [2]

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(b) For the lambda baryon Λ^0, a student proposes a possible decay of Λ^0 as shown.

$$\Lambda^0 \rightarrow p + K^-$$

The quark content of the K^- meson is $\bar{u}s$.

(i) Discuss, with reference to strangeness and baryon number, why this proposal is feasible. [4]

Strangeness:

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Baryon number:

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(Option D continues on the following page)

(Option D, question 13 continued)

(ii) Another interaction is

$$\Lambda^0 \rightarrow p + \pi^- .$$

In this interaction strangeness is found **not** to be conserved. Deduce the nature of this interaction. [1]

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(iii) The exchange particle involved in the interaction has a rest mass 80.4 GeV c^{-2}. Calculate the range of the weak interaction. [2]

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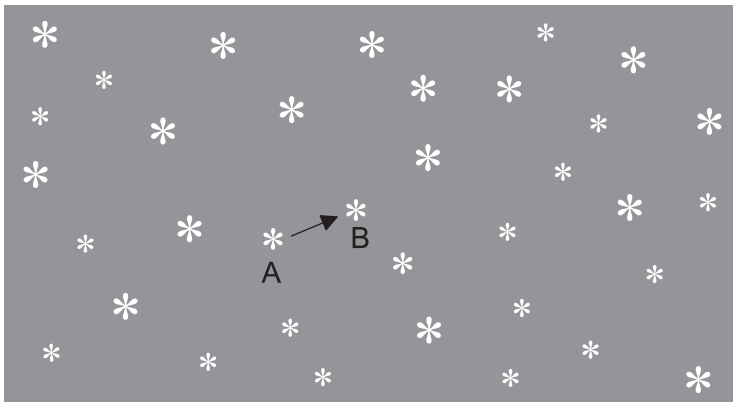
End of Option D

Option E — Astrophysics

14. This question is about determining the distance to a nearby star.

Two photographs of the night sky are taken, one six months after the other. When the photographs are compared, one star appears to have shifted from position A to position B, relative to the other stars.



(a) Outline why the star appears to have shifted from position A to position B. [1]

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(Option E continues on the following page)

(Option E, question 14 continued)

(b) The observed angular displacement of the star is θ and the diameter of the Earth's orbit is *d*. The distance from the Earth to the star is *D*.

(i) Draw a diagram showing *d*, *D* and θ. [1]

(ii) Explain the relationship between *d*, *D* and θ. [2]

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(iii) One consistent set of units for *D* and θ are parsecs and arc-seconds.
State **one** other consistent set of units for this pair of quantities. [1]

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(Option E continues on the following page)

(Option E, question 14 continued)

(c) Suggest whether the distance from Earth to this star can be determined using spectroscopic parallax. [1]

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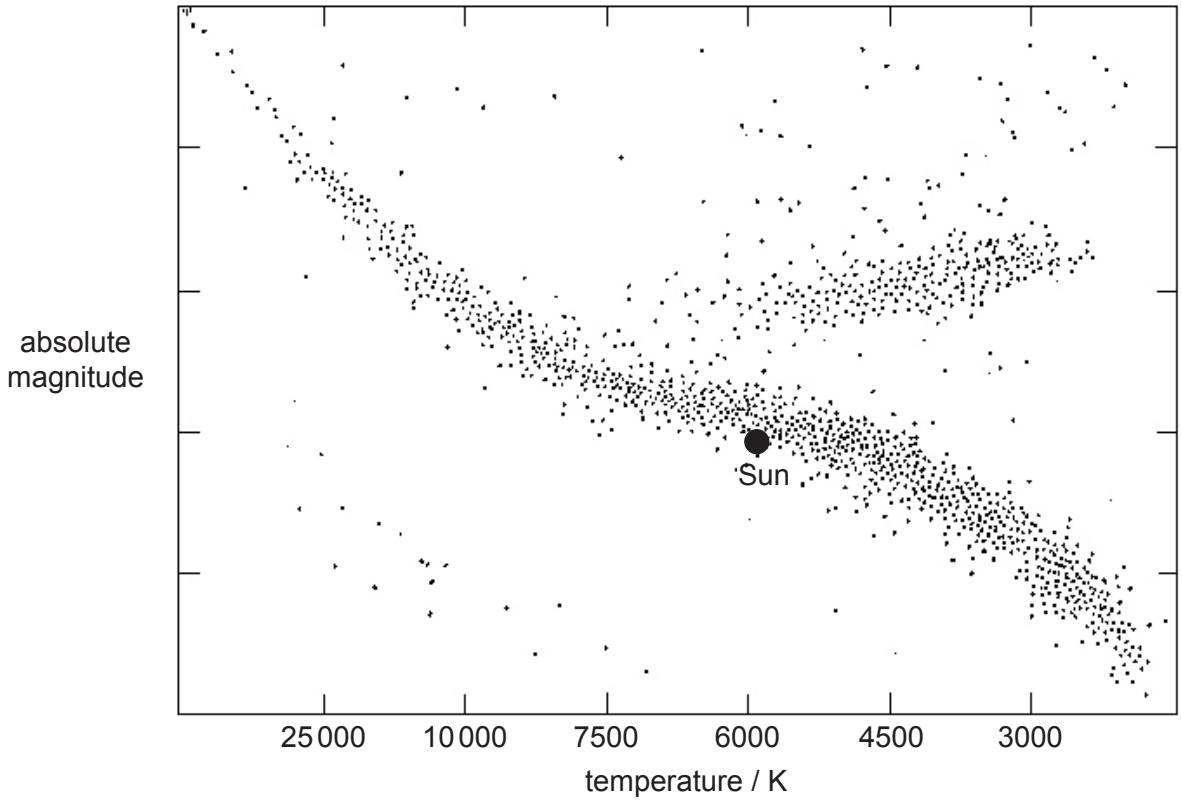
(Option E continues on the following page)

(Option E continued)

15. This question is about the Hertzsprung–Russell (HR) diagram and the Sun.

A Hertzsprung–Russell (HR) diagram is shown.



(a) Explain why absolute magnitude rather than apparent magnitude is used for the vertical axis on an HR diagram. [2]

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(Option E continues on the following page)

(Option E, question 15 continued)

(b) Outline why the scale selected for temperature on the HR diagram is **not** linear. [2]

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(c) The following data are given for the Sun and a star Vega.

Luminosity of the Sun	$= 3.85 \times 10^{26}\,\text{W}$
Luminosity of Vega	$= 1.54 \times 10^{28}\,\text{W}$
Surface temperature of the Sun	$= 5800\,\text{K}$
Surface temperature of Vega	$= 9600\,\text{K}$

Determine, using the data, the radius of Vega in terms of solar radii. [3]

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(d) Outline how observers on Earth can determine experimentally the temperature of a distant star. [3]

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(Option E continues on the following page)

(Option E continued)

16. This question is about cosmic microwave background (CMB) radiation.

One of Newton's assumptions was that the universe is static. The peak intensity of the cosmic microwave background (CMB) radiation has a wavelength of 1.06 mm.

(a) Show that this corresponds to a temperature around 3 K. [2]

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(b) Suggest how the discovery of the CMB in the microwave region contradicts Newton's assumption of the static universe. [2]

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End of Option E

Option F — Communications

17. This question is about modulation and satellite communication.

(a) State what is meant by modulation. [1]

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(b) A telephone call is transmitted as a radio signal from Europe to an explorer in South America.

(i) Outline why amplitude modulation (AM) is most suitable for this transmission. [2]

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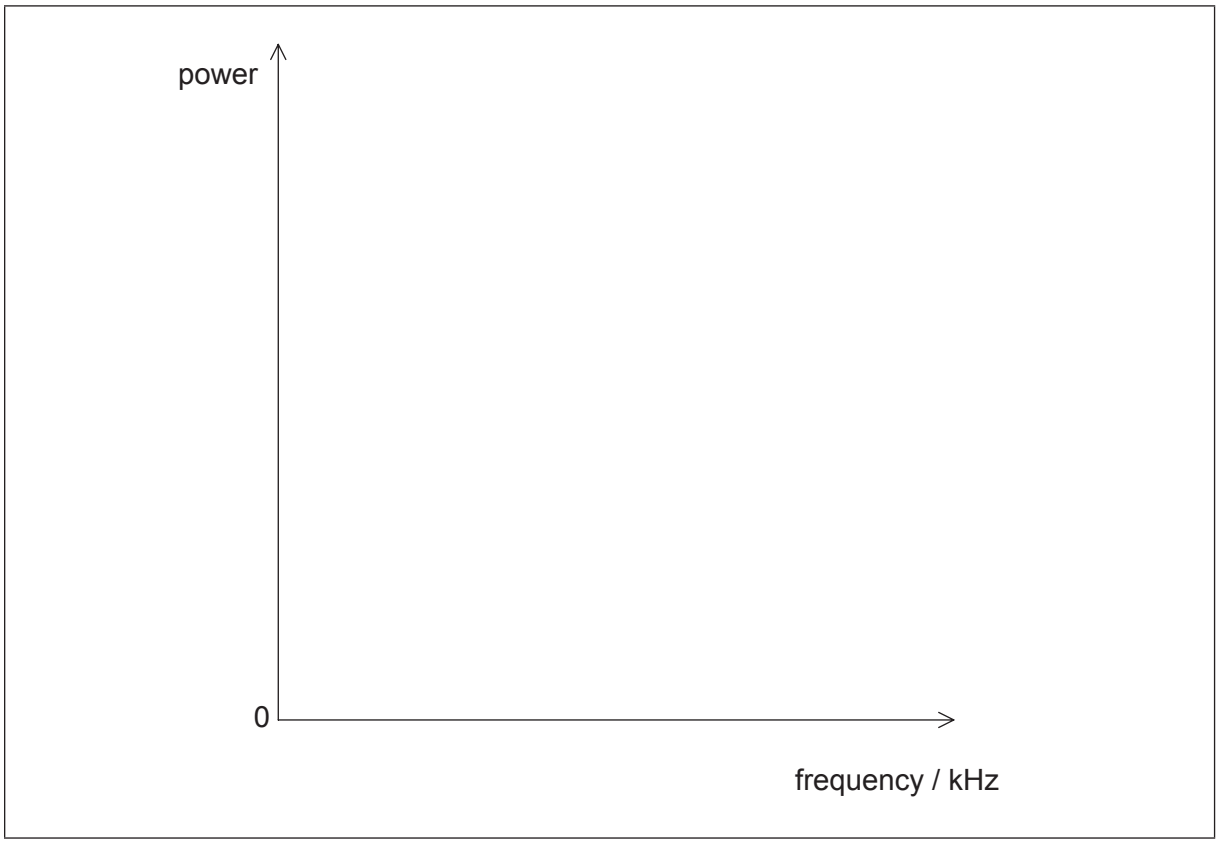
(Option F continues on the following page)

(Option F, question 17 continued)

(ii) A carrier wave of frequency 2.5 MHz is used to transmit a signal wave of frequency 40 kHz. Sketch a power spectrum of the AM carrier wave. [2]



(iii) The radio signal must be broadcast within a frequency band between 2.4 MHz and 2.8 MHz. The radio transmits a maximum signal frequency of 40 kHz. Calculate the number of radio signals that can be transmitted within the band. [1]

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(Option F continues on the following page)

(Option F, question 17 continued)

(c) Signals can be transmitted using either geostationary or polar-orbiting satellites. Discuss **one** advantage for each type of satellite. [4]

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Polar-orbiting:

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(Option F continues on the following page)

(Option F continued)

18. This question is about sampling and fibre optics.

Time-division multiplexing is used to transmit multiple signals along an optic fibre.

(a) (i) Describe how time-division multiplexing is achieved. [2]

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(ii) Cost is one advantage of time-division multiplexing. State **one** other advantage of time-division multiplexing. [1]

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(Option F continues on the following page)

(Option F, question 18 continued)

(b) An audio signal is sampled at a sampling frequency of 4.0 kHz. Each sample is converted to an 8-bit binary number. Each bit in the sample takes 8.0 μs to input into the fibre. Determine the maximum number of signals that can be transmitted along the fibre using time-division multiplexing. [4]

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(c) An optic fibre has length 3.0×10^4 m and attenuation per unit length 0.080 dB km^{-1}. Calculate the minimum input power of the signal if the output power is not to fall below 2.0 mW. [3]

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End of Option F

Option G — Electromagnetic waves

19. This question is about some properties of light.

(a) A space tourist travels from the surface of the Earth. When she leaves the Earth at 12:00 midday the sky appears blue. When she arrives at the limits of the atmosphere one hour later, she observes the sky to be black. Describe the reason for the change in colour of the sky during this journey. [3]

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(b) Carbon dioxide is a gas which occurs naturally in the atmosphere. One of the natural frequencies of vibration of carbon dioxide has a period of 5×10^{-14} s.

Frequency of infrared radiation from the Sun = around 300 THz
Frequency of infrared radiation emitted from the Earth = around 30 THz

Radiated energy from the Sun is trapped within the system that consists of the Earth and its atmosphere. Using a calculation, outline the mechanisms that lead to this process. [3]

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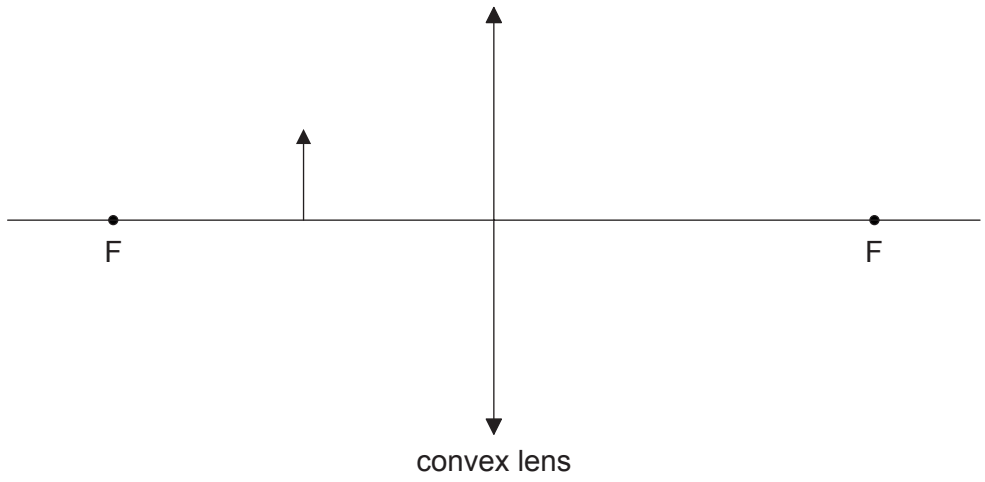
(Option G continues on the following page)

(Option G continued)

20. This question is about a converging (convex) lens.

Anna is unable to read small print in a newspaper. She uses a convex lens to read text more easily. Anna looks through the lens at an arrow on the page.



(a) (i) On the diagram, construct rays to locate the image of the arrow. The focal points of the lens are labelled F. [3]

(ii) Anna places a screen at the image position. Outline why she cannot see an image on the screen. [2]

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(Option G continues on the following page)

(Option G, question 20 continued)

(b) Anna uses the same lens with an illuminated object. She finds that a clear image of the object is formed when the lens is placed a distance of 20 cm from the screen. The lens has a focal length of 5 cm. Determine the magnification of the image. [3]

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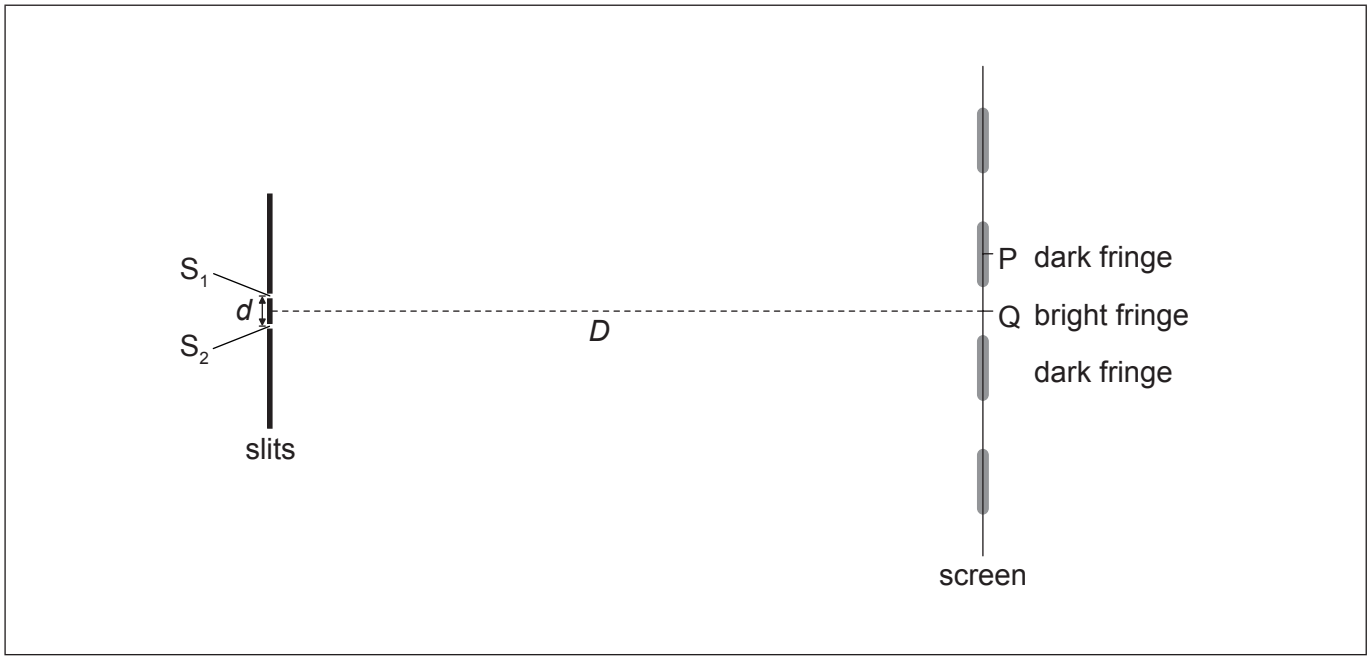
(Option G continues on the following page)

(Option G continued)

21. This question is about interference of light.

Coherent monochromatic light is incident on two narrow slits S_1 and S_2 a distance *d* apart. A screen is placed a distance *D* from the slits. An interference pattern of bright fringes and dark fringes appears on the screen. The central maximum is at Q.



(a) State **one** way to ensure that the light incident on the slits is coherent. [1]

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(b) Light emerging from S_1 and S_2 reaches the screen. Explain why the screen appears dark at point P. [2]

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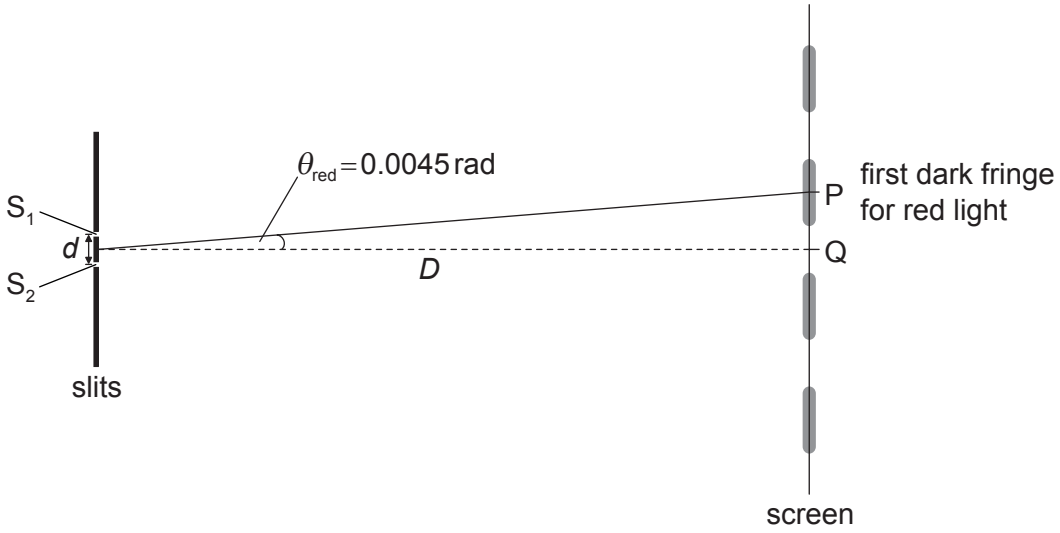
(Option G continues on the following page)

(Option G, question 21 continued)

(c) When red light of wavelength 660 nm is used the first fringe at P subtends an angle 0.0045 rad from midpoint of S_1 and S_2.



(i) Determine the change in angle when blue light of wavelength 440 nm is used. [2]

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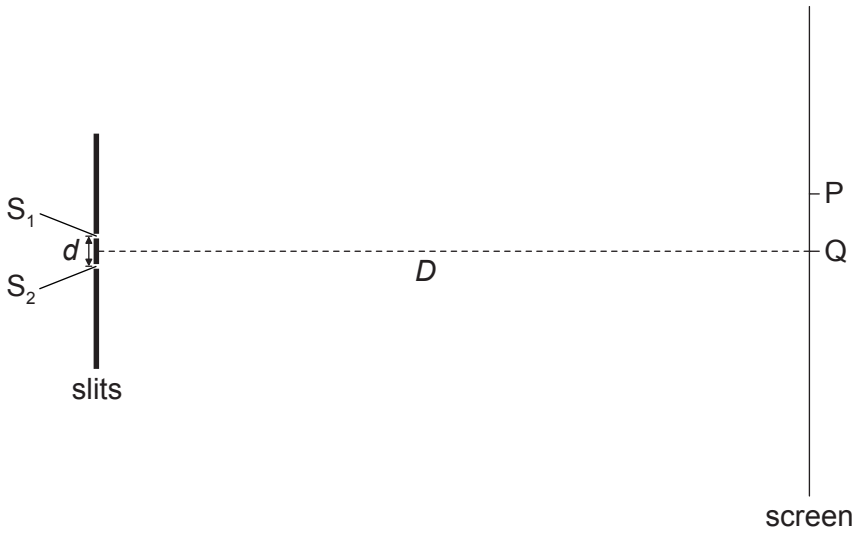
(ii) Using the diagram below, draw the approximate position of the first bright fringe using blue light. The position of the first dark fringe with red light is labelled P. [1]



End of Option G

Please **do not** write on this page.

Answers written on this page
will not be marked.