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PHYSICS
STANDARD LEVEL
PAPER 3

Candidate session number

Thursday 8 May 2014 (afternoon)

1 hour

Examination code

2	2	1	4	–	6	5	1	8

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 – 3
Option B — Quantum physics and nuclear physics	4 – 6
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Please **do not** write on this page.

Answers written on this page
will not be marked.

Option A — Sight and wave phenomena

1. This question is about the eye and sight.

   (a) Green light is shone onto a yellow filter. State the colour of the light that is transmitted through the filter. *[1]*

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   (b) (i) A white object is illuminated with equal intensities of red light and green light at the same time. State the colour that the object will appear to an observer. *[1]*

   ....

   (ii) Another white object is viewed in bright sunlight. Outline, with reference to the light-sensitive cells on the retina, why the object is seen more clearly when viewed directly rather than from the corner of the eye. *[2]*

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(Option A continues on the following page)

Turn over

(Option A continued)

2. This question is about the Doppler effect.

(a) Describe what is meant by the Doppler effect. *[2]*

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(b) A child on a carousel (merry-go-round) moves with a speed of $6.5\,\mathrm{m\,s^{-1}}$ along a horizontal circular path ABCDA. A stationary observer is at a large distance from the carousel.
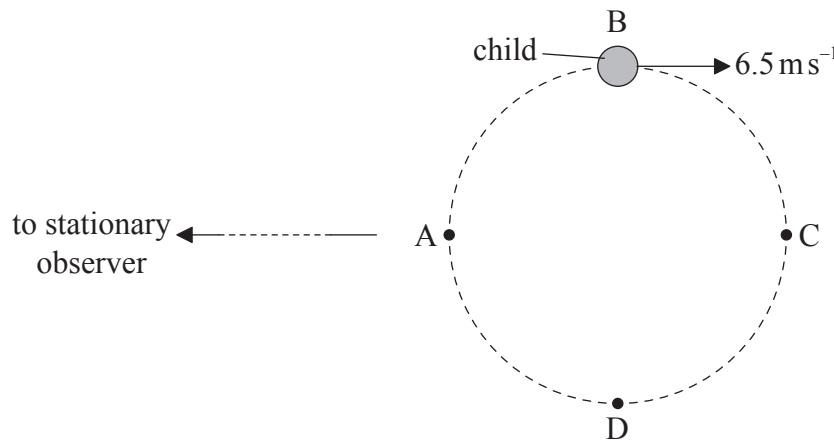
The child blows a whistle while moving from position B to position D. The whistle emits sound of frequency $850\,\mathrm{Hz}$. The speed of sound in air is $330\,\mathrm{m\,s^{-1}}$.

(i) Determine the minimum frequency of the sound heard by the observer. *[2]*

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(Option A continues on the following page)

40EP04

(Option A, question 2 continued)

    (ii)   Describe the variation of the frequency of the sound heard by the observer.   *[2]*

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3.   This question is about resolution and polarization.

    (a)   State the Rayleigh criterion.   *[2]*

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(Option A continues on the following page)
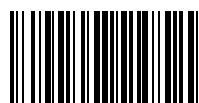
(Option A, question 3 continued)

(b)   A ship sails towards two stone towers built on land.

stone towers

ship

(not to scale)
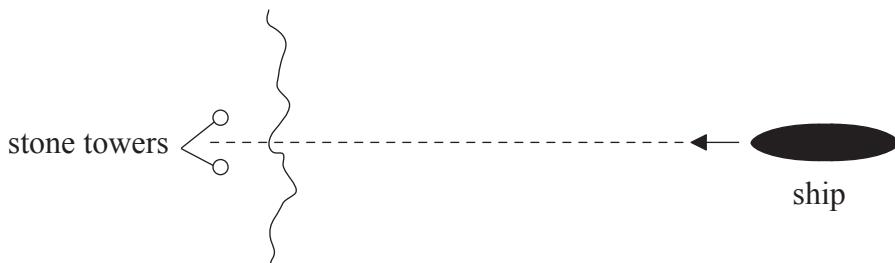
Emlyn, who is on the ship, views the towers. The pupils of Emlyn's eyes are each of diameter 2.0 mm. The average wavelength of the sunlight is 550 nm.

(i)   Calculate the angular separation of the two towers when the images of the towers are just resolved by Emlyn. *[1]*

(ii)   Emlyn can just resolve the images of the two towers when his distance from the towers is 11 km. Determine the distance between the two towers. *[2]*
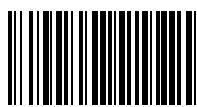
(Option A, question 3 continued)

(c)   The intensity of the sunlight suddenly increases. As a result, there is a change in the distance between Emlyn and the towers at which their images are just resolved. State and explain, with reference to the response of the eye, how this distance changes.   *[3]*

(d)   Emlyn puts on a pair of polarizing sunglasses. Explain how these sunglasses reduce the intensity of the light, reflected from the sea, that enters Emlyn's eyes.   *[2]*

End of Option A

Option B — Quantum physics and nuclear physics

4. This question is about wave–particle duality.

(a) Describe what is meant by the de Broglie hypothesis. *[2]*

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(b) A particle of mass 6.4×10^{-27} kg and charge 3.2×10^{-19} C is accelerated from rest through a potential difference of 25 kV.

(i) Calculate the kinetic energy of the particle. *[1]*

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(ii) Determine the de Broglie wavelength of the particle. *[3]*

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(Option B continues on the following page)

(Option B continued)

5. This question is about atomic spectra.

(a) Explain how atomic line spectra provide evidence for the existence of discrete electron energy levels in atoms. *[3]*

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(Option B continues on the following page)

Turn over

(Option B, question 5 continued)

(b)   The diagram shows some of the energy levels of a hydrogen atom.

energy / eV

-0.85

-1.51

-3.40
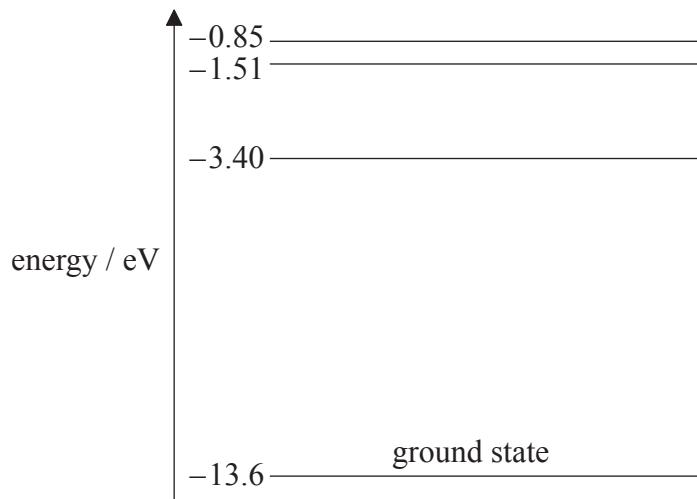
-13.6 ground state

(i)   Calculate the wavelength of the photon that will be emitted when an electron moves from the $-3.40\,\text{eV}$ energy level to the $-13.6\,\text{eV}$ energy level.   *[3]*

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(ii)   State and explain if it is possible for a hydrogen atom in the ground state to absorb a photon with an energy of $12.5\,\text{eV}$.   *[2]*

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(Option B continues on the following page)

40EP10

(Option B continued)

6. This question is about radioactive decay.

(a) Define the *decay constant* of a radioactive isotope. *[1]*

(b) Show that the decay constant λ is related to the half-life $T_{\frac{1}{2}}$ by the expression

$$\lambda T_{\frac{1}{2}} = \ln 2.$$

[2]

(c) Strontium-90 is a radioactive isotope with a half-life of 28 years. Calculate the time taken for 65 % of the strontium-90 nuclei in a sample of the isotope to decay. *[3]*

End of Option B

Option C — Digital technology

7. This question is about digital devices.

(a) A 22 V analogue signal is converted into a digital signal.

(i) Determine the binary number that corresponds to 22. *[1]*

(ii) Outline how this digital signal is stored on the compact disc (CD). *[2]*

(iii) Describe how the information stored on the CD is recovered. *[2]*

(Option C continues on the following page)

(Option C, question 7 continued)

(b) Digital information can also be stored on a charge-coupled device (CCD).

(i) Light incident on a pixel results in a potential difference being developed across the pixel. State the property of the incident light that is proportional to potential difference. *[1]*

....

(ii) Photons incident on the pixel of a particular CCD deliver an energy of 4.5×10^{-16} J to the pixel. The frequency of the photons is 6.2×10^{14} Hz. The quantum efficiency of a pixel is 84% and the capacitance of the pixel is 25 pF. Determine the potential difference developed across the pixel. *[4]*

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(Option C continues on the following page)

Turn over

(Option C continued)

8. This question is about operational amplifiers (op-amps).

(a) The diagram shows an inverting amplifier.
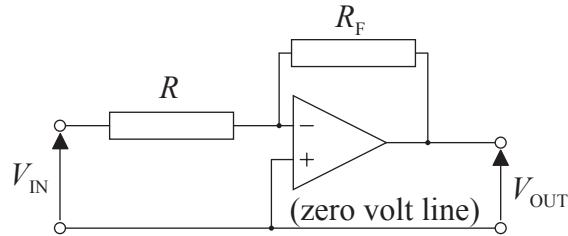
The op-amp operates with a power supply of ± 6.0 V. The resistance of R_F is 75 kΩ and the resistance of R is 15 kΩ.

(i) State **one** property of an ideal op-amp. *[1]*

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(ii) Determine the closed loop gain of the inverting amplifier. *[1]*

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(iii) Calculate the input voltage at which positive saturation is achieved. *[1]*

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(Option C continues on the following page)

(Option C, question 8 continued)

(b)   The input voltage V to the inverting amplifier in (a) varies with time t according to the graph.
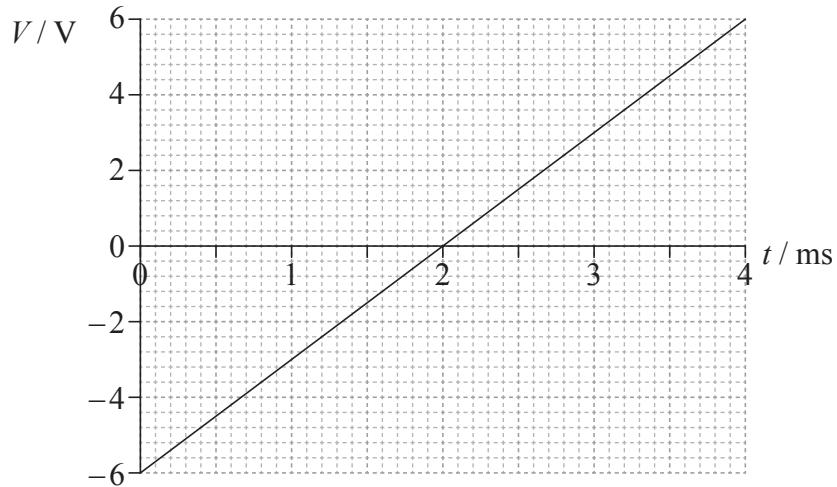
On the axes, sketch a graph to show how the output voltage varies with time.   *[3]*

9.   This question is about the mobile phone system.

A train passenger in France has a 10 minute conversation on her mobile phone with a friend in Canada. Outline the role of base stations, the cellular exchange and the public switched telephone network (PSTN) in this phone call.   *[4]*

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End of Option C

Turn over

Option D — Relativity and particle physics

10. This question is about relativistic kinematics.

The diagram shows a spaceship as it moves past Earth on its way to a planet P. The planet is at rest relative to Earth.
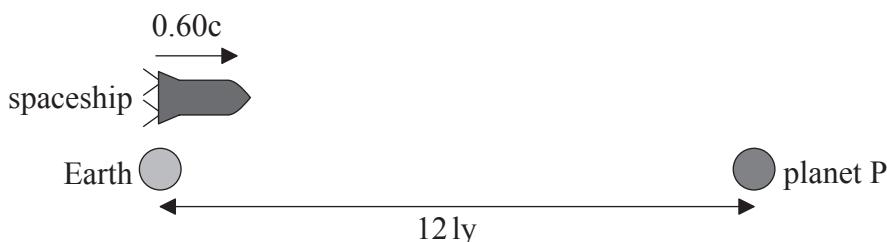
The distance between the Earth and planet P is 12 ly as measured by observers on Earth. The spaceship moves with speed 0.60c relative to Earth.

Consider two events:

Event 1: when the spaceship is above Earth
Event 2: when the spaceship is above planet P

Judy is in the spaceship and Peter is at rest on Earth.

(a) State the reason why the time interval between event 1 and event 2 is a proper time interval as measured by Judy. *[1]*

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(b) (i) Calculate the time interval between event 1 and event 2 according to Peter. *[1]*

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(Option D continues on the following page)

40EP16

(Option D, question 10 continued)

(ii)   Calculate the time interval between event 1 and event 2 according to Judy.   *[2]*

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(c)   Judy considers herself to be at rest. According to Judy, the Earth and planet P are moving to the left.

(i)   Calculate, according to Judy, the distance separating the Earth and planet P.   *[1]*

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(ii)   Using your answers to (b)(ii) and (c)(i), determine the speed of planet P relative to the spaceship.   *[1]*

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(iii)   Comment on your answer to (c)(ii).   *[1]*

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(Option D continues on the following page)

(Option D, question 10 continued)

(d) At a point half-way between the Earth and planet P, the spaceship passes a space station that is at rest relative to the Earth and planet P. At that instant, radio signals are sent towards the spaceship from the Earth and planet P. The signals are emitted simultaneously according to an observer S at rest on the space station.
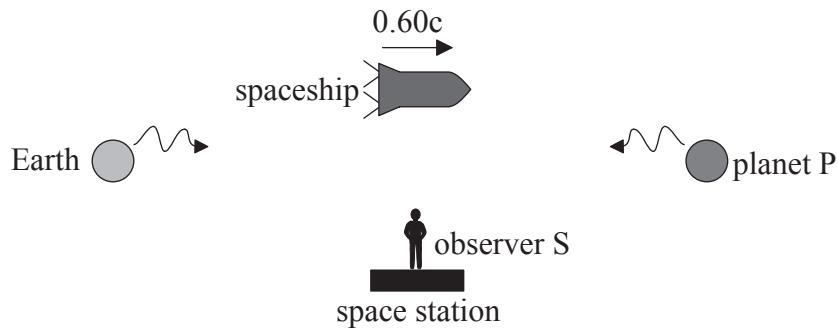
Determine, according to Judy in the spaceship, which signal is emitted first. *[3]*

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(Option D continues on the following page)

(Option D continued)

11. This question is about fundamental interactions.

    (a)   The kaon is a hadron whose quark structure is $K^+ = u\bar{s}$.

        (i)   State and explain whether the Pauli exclusion principle applies to kaons.   *[2]*

        (ii)   Energy is supplied to the kaon in order to break up the particle into its constituent quarks. Predict, by reference to quark colour, what will happen as more and more energy is provided to the K^+.   *[3]*

(Option D continues on the following page)

Turn over

(Option D, question 11 continued)

(b) The kaon $(K^+ = u\overline{s})$ decays into an antimuon and a neutrino as shown by the Feynman diagram.
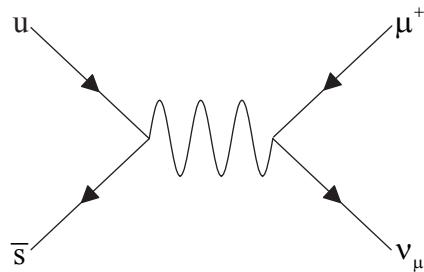
(i) Explain why the virtual particle in this Feynman diagram must be a weak interaction exchange particle. *[2]*

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(ii) The mass of the virtual particle in (b)(i) is approximately $80\,\text{GeV}\,c^{-2}$. Estimate the range of the weak interaction. *[2]*

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(c) A student claims that the K^+ is produced in neutron decays according to the reaction $n \rightarrow K^+ + e^-$. State **one** reason why this claim is false. *[1]*

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End of Option D
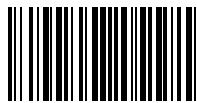
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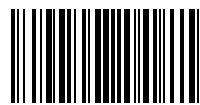
Option E — Astrophysics

12. This question is about objects in the universe.

(a) State **one** difference between

(i) a main sequence star and a planet. *[1]*

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....

(ii) a stellar cluster and a constellation. *[1]*

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....

(Option E continues on the following page)

(Option E, question 12 continued)

(b)   State how

(i)   it is known that main sequence stars are made predominantly of hydrogen.   *[1]*

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(ii)   a main sequence star remains in equilibrium despite it having a great mass.   *[1]*

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(c)   The graph shows the variation with wavelength of the intensity of a main sequence star.
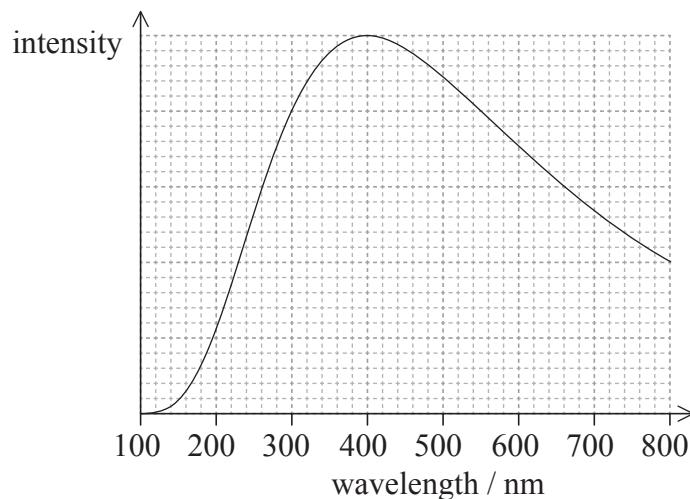
Calculate the surface temperature of this star.   *[2]*

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(Option E continued)

13. This question is about a Cepheid star.

(a) The graph shows the variation with time t of the apparent magnitude m of a particular Cepheid star.
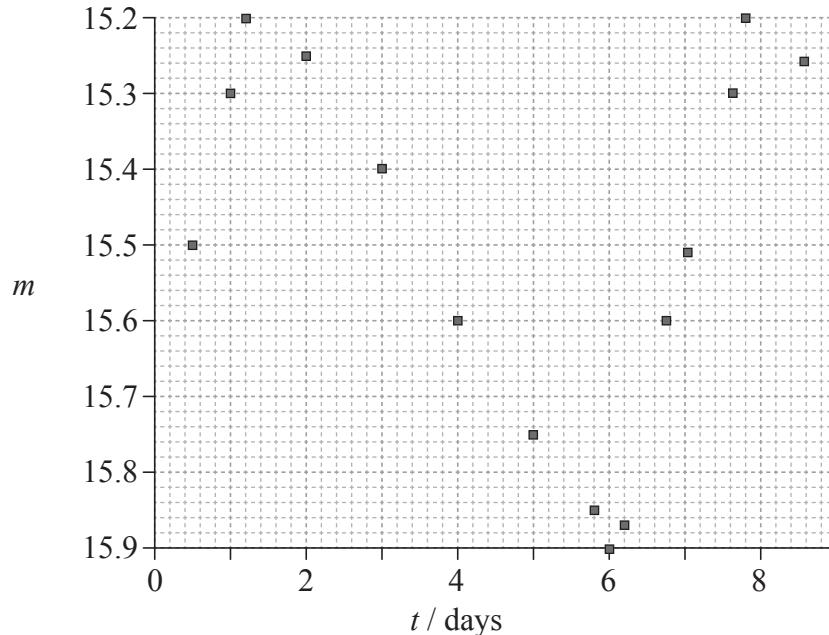
State

(i) what apparent magnitude is a measure of. *[1]*

. . . .

(ii) the reason for the variation of the star's apparent magnitude. *[1]*

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(Option E continues on the following page)

(Option E, question 13 continued)

(b) The period T, in days, of variation of the apparent magnitude is related to the average absolute magnitude M of the star in (a) through the equation below.

$$M = -(2.81 \times \lg T) - 1.43$$

Determine the distance to the star.   *[5]*

(c) The apparent brightness of the Cepheid star is $b = 1.5 \times 10^{-14}\ \mathrm{W\,m^{-2}}$. Determine the luminosity of the star.   *[3]*

(Option E continues on the following page)

Turn over

(Option E continued)

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

(a) State **two** characteristics of the cosmic microwave background (CMB) radiation. *[2]*

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2. . . . .
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(b) Explain how CMB radiation is evidence for the Big Bang model of an expanding universe. *[2]*

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End of Option E

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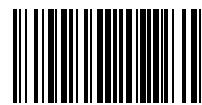
Option F — Communications

**15.** This question is about modulation.

(a) (i) Explain what is meant by frequency modulation (FM). *[2]*

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(ii) The graph shows the variation with time t of the voltage V of a frequency modulated carrier wave. The amplitude of the signal wave is 1.0 V.
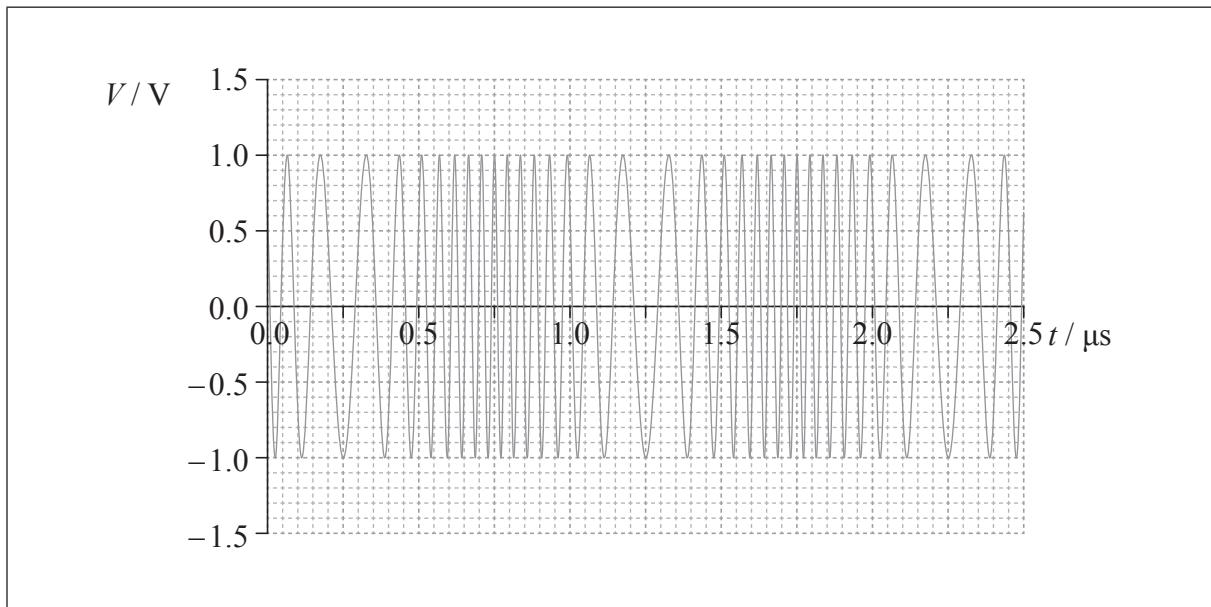
On the axes, draw a sketch graph to show the variation with time t of the voltage of the signal wave. *[2]*

(Option F continues on the following page)
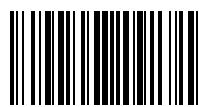
(Option F, question 15 continued)

(b) Using the graph in (a)(ii), determine the frequency of the

   (i) carrier wave.   *[1]*

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   . . . .

   (ii) signal wave.   *[2]*

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(c) State **one** advantage and **one** disadvantage of FM modulation compared to amplitude modulation (AM).   *[2]*

   Advantage:

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   . . . .
   . . . .

   Disadvantage:

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   . . . .
   . . . .

(Option F continues on the following page)

Turn over

(Option F continued)

16. This question is about sampling.

An analogue signal is sampled. The graph shows the variation with time t of the voltage V of each sample.

The voltage in each sample is rounded to the nearest integer.

(a) Determine the sampling frequency. *[2]*

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(Option F continues on the following page)

(Option F, question 16 continued)

(b) The highest voltage in a sample is 12 V. Determine the minimum number of bits that are required in order to represent each sample. *[2]*

(c) Calculate the binary equivalent of the seventh sample. *[1]*

(Option F continues on the following page)

(Option F continued)

17. This question is about digital transmission and optical fibres.

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

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(Option F, question 17 continued)

(b) A digital signal is to be transmitted along an optic fibre. The signal to noise ratio $\left(\text{that is } 10\lg\dfrac{P_{signal}}{P_{noise}}\right)$ in the fibre must not fall below 35 dB.

The following data are available.

Attenuation per unit length of the optic fibre $= 2.6\,\text{dB km}^{-1}$

Power of the input signal is P_{signal} $= 88\,\text{mW}$

Noise power in the fibre is constant at P_{noise} $= 52\,\text{pW}$

(i) Determine, using the data, the greatest distance the signal can travel before it must be amplified. *[3]*

(ii) The optic fibre has a total length of 5600 km. The total transmission time along the length of the fibre is 28 ms. Estimate the refractive index of the core of the fibre. *[2]*

End of Option F

Turn over

**Option G — Electromagnetic waves**

18. This question is about a magnifying glass and a telescope.

(a) A thin converging (convex) lens is used as a magnifying glass. Object O is placed between a focal point of the lens and the centre of the lens. The focal points of the lens are shown, labelled F.

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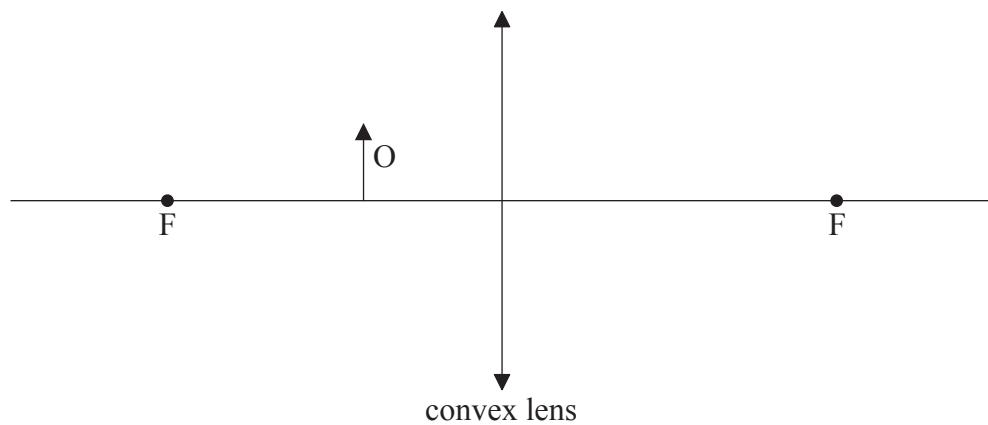
(i) Define the term *focal point*. *[2]*

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(ii) On the diagram, construct rays to locate the position of the image of the object. Label the image I. *[3]*

(Option G continues on the following page)
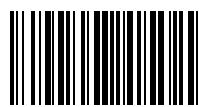
(Option G, question 18 continued)

(b) The position of the lens in (a) is changed so that a virtual image of the object is formed at the near point of the eye. The eye is very close to the lens.

(i) Define the term *near point*. *[1]*

(ii) Outline the advantage of having the image positioned at the near point of the eye. *[1]*

(c) The lens in (a) has a focal length of 6.0 cm and is now used as the eyepiece of an astronomical telescope. The objective lens of the telescope has a focal length of 90 cm. The telescope is used in normal adjustment.

(i) State the separation of the objective lens and the eyepiece lens. *[1]*

(ii) Determine the angular magnification of the telescope. *[2]*

*(Option G continues on the following page)*

Turn over

(Option G continued)

19. This question is about interference.

Light from a laser is incident on two identical parallel slits. The light from the two slits produces a fringe pattern on a screen.

A central bright fringe is produced at C. The next bright fringe is produced at A. There is a dark fringe at B.

(a) The light from the laser is coherent and monochromatic. Outline what is meant by the term

   (i) coherent. *[1]*

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   (ii) monochromatic. *[1]*

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(Option G continues on the following page)
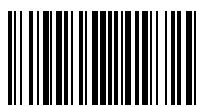
(Option G, question 19 continued)

(b)   State the phase difference between the light waves from the two slits that meet at B.   *[1]*

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(c)   The distance from the two slits to the screen is 1.5 m. The distance BC is 1.8 mm and the distance between the slits is 0.30 mm.

(i)   Show that the laser produces light of wavelength equal to 720 nm.   *[3]*

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(ii)   State the path difference, in metres, between the waves that meet at B.   *[1]*

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(Option G continues on the following page)

Turn over

(Option G, question 19 continued)

(d)   The light from the laser is now incident normally on a diffraction grating. The angle
between the third-order intensity maxima is 78°.

light, $\lambda = 720\,\text{nm}$

third-order, $n = 3$

78°

third-order, $n = 3$

diffraction grating
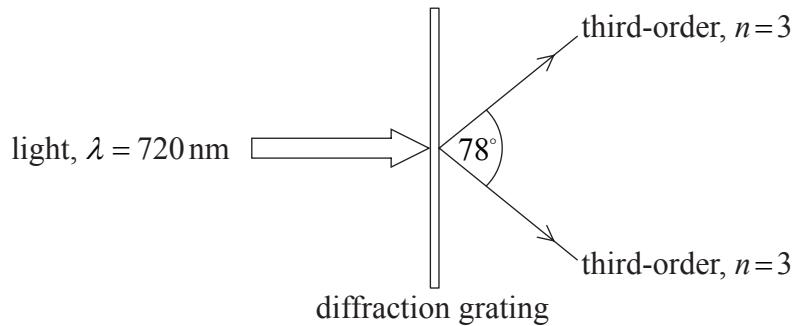
Determine the number of lines per metre of the diffraction grating.   *[3]*

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End of Option G

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