Diploma Programme
Programme du diplôme
Programa del Diploma

Physics
Higher level
Paper 3

Tuesday 16 May 2017 (morning)

Candidate session number

1 hour 15 minutes

Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answers must be written within the answer 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 **[45 marks]**.

Section A	Questions
Answer all questions.	1 – 2

Section B	Questions
Answer all of the questions from one of the options.	
Option A — Relativity	3 – 6
Option B — Engineering physics	7 – 10
Option C — Imaging	11 – 13
Option D — Astrophysics	14 – 17

31 pages

2217 – 6509

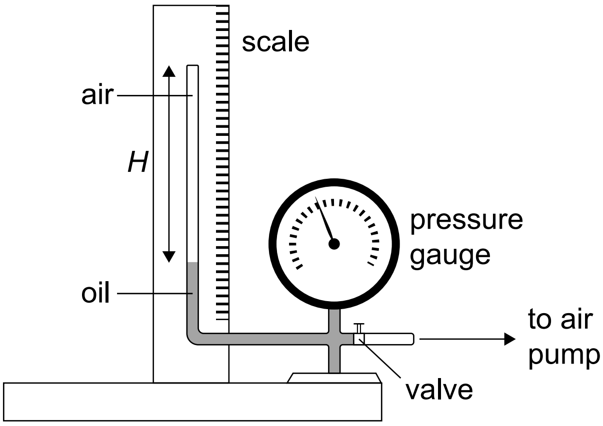
Please **do not** write on this page.

Answers written on this page
will not be marked.

Section A

Answer **all** questions. Answers must be written within the answer boxes provided.

1. The equipment shown in the diagram was used by a student to investigate the variation with volume, of the pressure *p* of air, at constant temperature. The air was trapped in a tube of constant cross-sectional area above a column of oil.



The pump forces oil to move up the tube decreasing the volume of the trapped air.

(a) The student measured the height *H* of the air column and the corresponding air pressure *p*. After each reduction in the volume the student waited for some time before measuring the pressure. Outline why this was necessary. [1]

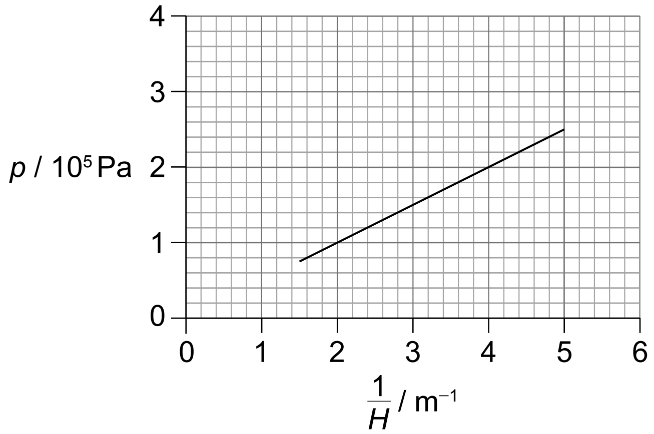
. . . .

. . . .

(This question continues on the following page)

(Question 1 continued)

(b) The following graph of p versus $\frac{1}{H}$ was obtained. Error bars were negligibly small.



The equation of the line of best fit is $p = a + \frac{b}{H}$.

Determine the value of b including an appropriate unit. [3]

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(c) Outline how the results of this experiment are consistent with the ideal gas law at constant temperature. [2]

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question 1 continued)

(d) The cross-sectional area of the tube is $1.3 \times 10^{-3}\,m^2$ and the temperature of air is 300 K. Estimate the number of moles of air in the tube. [2]

. . . .

. . . .

. . . .

. . . .

(e) The equation in (b) may be used to predict the pressure of the air at extremely large values of $\frac{1}{H}$. Suggest why this will be an unreliable estimate of the pressure. [2]

. . . .

. . . .

. . . .

. . . .

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

Answers written on this page
will not be marked.

2. (a) In a simple pendulum experiment, a student measures the period T of the pendulum many times and obtains an average value $T = (2.540 \pm 0.005)$ s. The length L of the pendulum is measured to be $L = (1.60 \pm 0.01)$ m.

Calculate, using $g = \frac{4\pi^2 L}{T^2}$, the value of the acceleration of free fall, including its uncertainty. State the value of the uncertainty to one significant figure. [3]

. . . .

. . . .

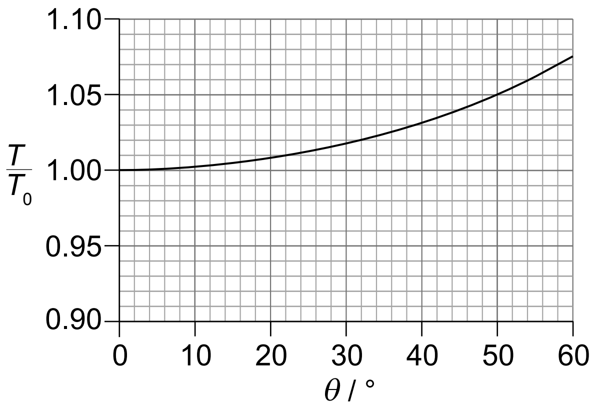
. . . .

. . . .

. . . .

. . . .

(b) In a different experiment a student investigates the dependence of the period T of a simple pendulum on the amplitude of oscillations θ. The graph shows the variation of $\frac{T}{T_0}$ with θ, where T_0 is the period for small amplitude oscillations.



The period may be considered to be independent of the amplitude θ as long as $\frac{T - T_0}{T_0} < 0.01$. Determine the maximum value of θ for which the period is independent of the amplitude. [2]

. . . .

. . . .

. . . .

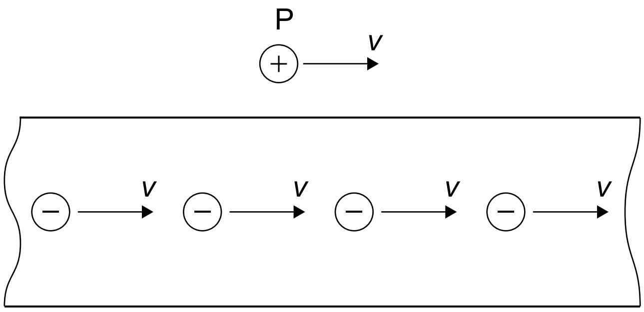
. . . .

Section B

Answer **all** of the questions from **one** of the options. Answers must be written within the answer boxes provided.

Option A — Relativity

3. A long current-carrying wire is at rest in the reference frame S of the laboratory. A positively charged particle P outside the wire moves with velocity v relative to S. The electrons making up the current in the wire move with the same velocity v relative to S.



current-carrying wire

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

. . . .

. . . .

(b) State and explain whether the force experienced by P is magnetic, electric or both

(i) in reference frame S. [2]

. . . .

. . . .

. . . .

. . . .

(Option A continues on the following page)

(Option A, question 3 continued)

(ii) in the rest frame of P. [3]

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(Option A continues on page 11)

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

Answers written on this page
will not be marked.

(Option A continued)

4. An observer P sitting in a train moving at a speed v measures that his journey takes a time Δt_P. An observer Q at rest with respect to the ground measures that the journey takes a time Δt_Q.

(a) State which of the two time intervals is a proper time. [1]

. . . .

. . . .

(b) Calculate the speed v of the train for the ratio $\frac{\Delta t_P}{\Delta t_Q} = 0.30$. [2]

. . . .

. . . .

. . . .

. . . .

(c) Later the train is travelling at a speed of 0.60c. Observer P measures the length of the train to be 125 m. The train enters a tunnel of length 100 m according to observer Q.

Show that the length of the train according to observer Q is 100 m. [2]

. . . .

. . . .

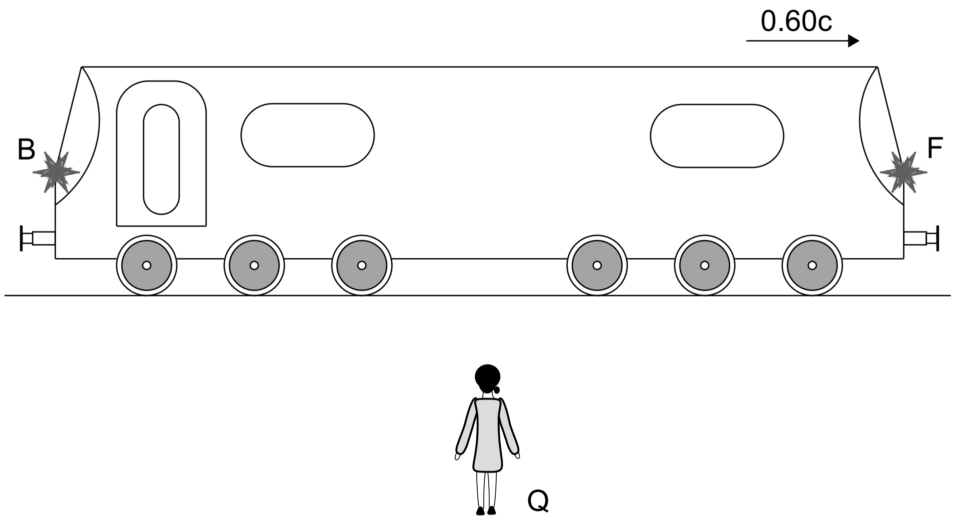
. . . .

. . . .

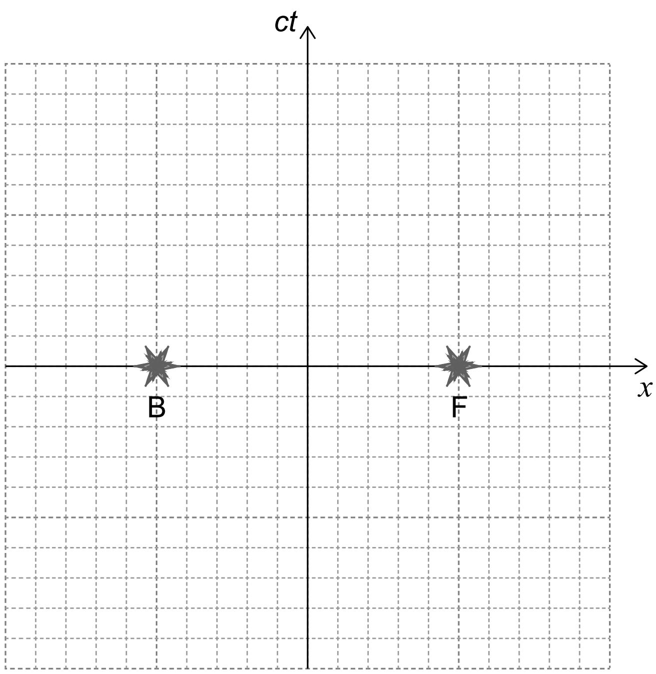
(Option A continues on the following page)

(Option A, question 4 continued)

(d) According to Q there is an instant at which the train is completely within the tunnel. At that instant two lights at the front and the back of the train are turned on simultaneously according to Q.



The spacetime diagram according to observer Q shows event B (back light turns on) and event F (front light turns on).



(i) Draw the time ct' and space x' axes for observer P's reference frame on the spacetime diagram. [1]

(Option A continues on the following page)

(Option A, question 4 continued)

(ii) Deduce, using the spacetime diagram, which light was turned on first according to observer P. [3]

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(iii) Apply a Lorentz transformation to show that the time difference between events B and F according to observer P is 2.5×10^{-7} s. [1]

. . . .

. . . .

(iv) Demonstrate that the spacetime interval between events B and F is invariant. [2]

. . . .

. . . .

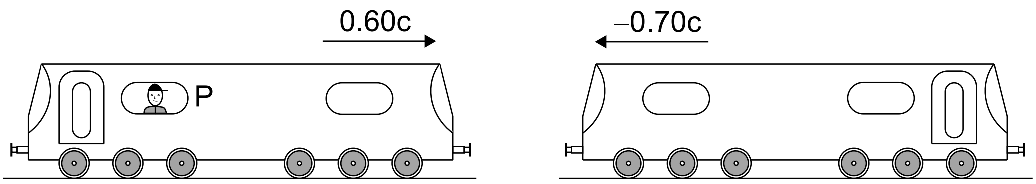
. . . .

. . . .

(Option A continues on the following page)

(Option A, question 4 continued)

(e) A second train is moving at a velocity of –0.70c with respect to the ground.



Calculate the speed of the second train relative to observer P. [2]

. . . .
. . . .
. . . .
. . . .

5. A proton is accelerated from rest through a potential difference *V* to a speed of 0.86c.

(a) Calculate the potential difference *V*. [3]

. . . .
. . . .
. . . .
. . . .
. . . .
. . . .

(Option A continues on the following page)

(Option A, question 5 continued)

(b) The proton collides with an antiproton moving with the same speed in the opposite direction. As a result both particles are annihilated and two photons of equal energy are produced.

Determine the momentum of one of the photons. [3]

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

6. In an experiment a source of iron-57 emits gamma rays of energy 14.4 keV. A detector placed 22.6 m vertically above the source measures the frequency of the gamma rays.

(a) Calculate the expected shift in frequency between the emitted and the detected gamma rays. [2]

. . . .

. . . .

. . . .

. . . .

(b) Explain whether the detected frequency would be greater or less than the emitted frequency. [2]

. . . .

. . . .

. . . .

. . . .

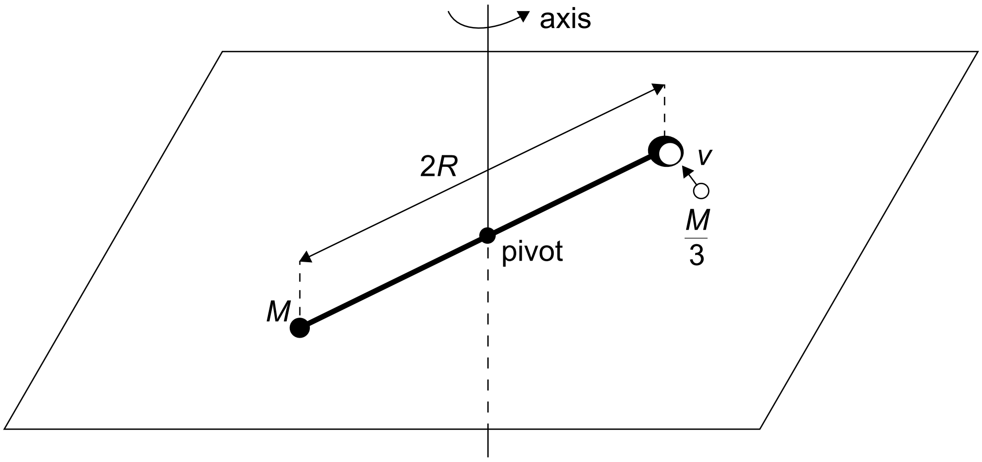
End of Option A

Option B — Engineering physics

7. A horizontal rigid bar of length $2R$ is pivoted at its centre. The bar is free to rotate in a horizontal plane about a vertical axis through the pivot. A point particle of mass M is attached to one end of the bar and a container is attached to the other end of the bar.

A point particle of mass $\frac{M}{3}$ moving with speed v at right angles to the rod collides with the container and gets stuck in the container. The system then starts to rotate about the vertical axis.

The mass of the rod and the container can be neglected.



(a) (i) Write down an expression, in terms of M, v and R, for the angular momentum of the system about the vertical axis just before the collision. [1]

. . . .

. . . .

(ii) Just after the collision the system begins to rotate about the vertical axis with angular velocity ω. Show that the angular momentum of the system is equal to $\frac{4}{3}MR^2\omega$. [1]

. . . .

. . . .

(Option B continues on the following page)

(Option B, question 7 continued)

(iii) Hence, show that $\omega = \dfrac{v}{4R}$. [1]

. . . .
. . . .

(iv) Determine in terms of *M* and *v* the energy lost during the collision. [3]

. . . .
. . . .
. . . .
. . . .
. . . .
. . . .

(b) A torque of 0.010 N m brings the system to rest after a number of revolutions. For this case $R = 0.50\,\text{m}$, $M = 0.70\,\text{kg}$ and $v = 2.1\,\text{m s}^{-1}$.

(i) Show that the angular deceleration of the system is $0.043\,\text{rad s}^{-2}$. [1]

. . . .
. . . .

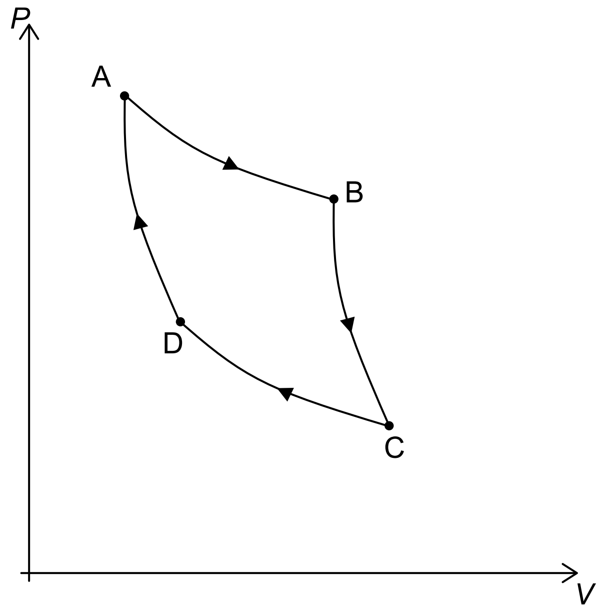
(ii) Calculate the number of revolutions made by the system before it comes to rest. [3]

. . . .
. . . .
. . . .
. . . .
. . . .
. . . .

(Option B continues on the following page)

(Option B continued)

8. The *P*–*V* diagram of the Carnot cycle for a monatomic ideal gas is shown.



(a) State what is meant by an adiabatic process. [1]

. . . .

. . . .

(b) Identify the two isothermal processes. [1]

. . . .

. . . .

(c) The system consists of 0.150 mol of a gas initially at A. The pressure at A is 512 kPa and the volume is $1.20 \times 10^{-3}\,m^3$.

(i) Determine the temperature of the gas at A. [2]

. . . .

. . . .

. . . .

. . . .

(Option B continues on the following page)

(Option B, question 8 continued)

(ii) The volume at B is $2.30 \times 10^{-3}\,\text{m}^3$. Determine the pressure at B. [2]

. . . .

. . . .

. . . .

. . . .

(d) At C the volume is V_C and the temperature is T_C.

(i) Show that $P_B V_B^{\frac{5}{3}} = nRT_C V_C^{\frac{2}{3}}$. [1]

. . . .

. . . .

. . . .

(ii) The volume at C is $2.90 \times 10^{-3}\,\text{m}^3$. Calculate the temperature at C. [2]

. . . .

. . . .

. . . .

. . . .

(e) State a reason why a Carnot cycle is of little use for a practical heat engine. [1]

. . . .

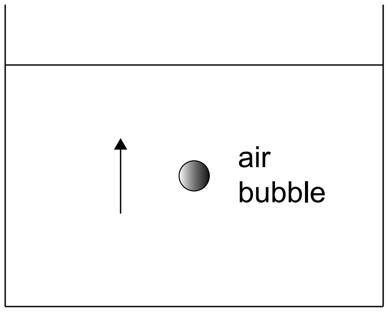
. . . .

(Option B continues on the following page)

(Option B continued)

9. An air bubble has a radius of 0.25 mm and is travelling upwards at its terminal speed in a liquid of viscosity 1.0×10^{-3} Pa s.

The density of air is $1.2\,\text{kg m}^{-3}$ and the density of the liquid is $1200\,\text{kg m}^{-3}$.



(a) Explain the origin of the buoyancy force on the air bubble. [2]

. . . .

. . . .

. . . .

. . . .

(b) With reference to the ratio of weight to buoyancy force, show that the weight of the air bubble can be neglected in this situation. [2]

. . . .

. . . .

. . . .

. . . .

(c) Calculate the terminal speed. [2]

. . . .

. . . .

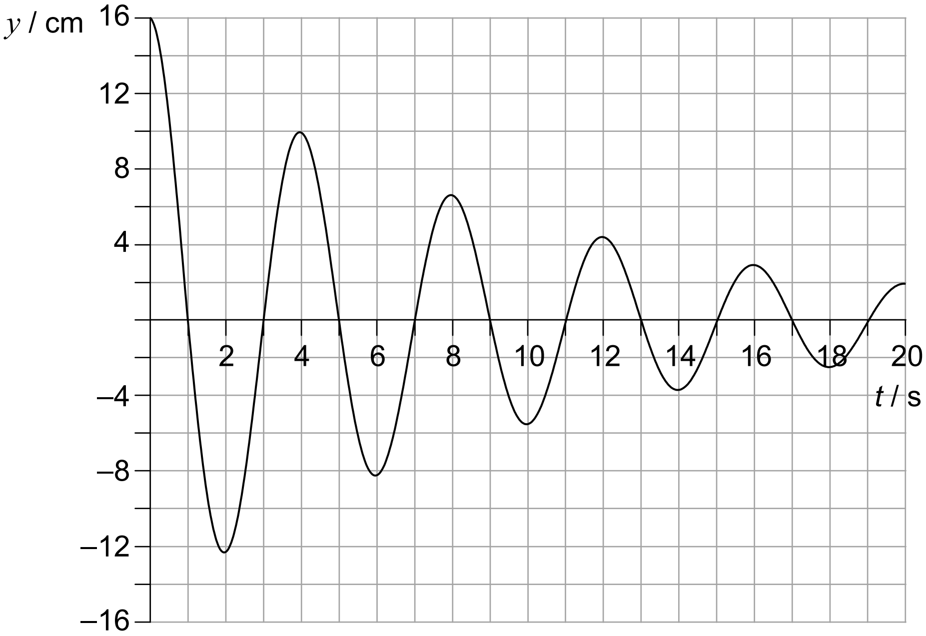
. . . .

. . . .

(Option B continues on the following page)

(Option B continued)

10. The graph below shows the displacement y of an oscillating system as a function of time t.



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

. . . .

. . . .

(b) Calculate the Q factor for the system. [1]

. . . .

. . . .

(c) The Q factor of the system increases. State and explain the change to the graph. [2]

. . . .

. . . .

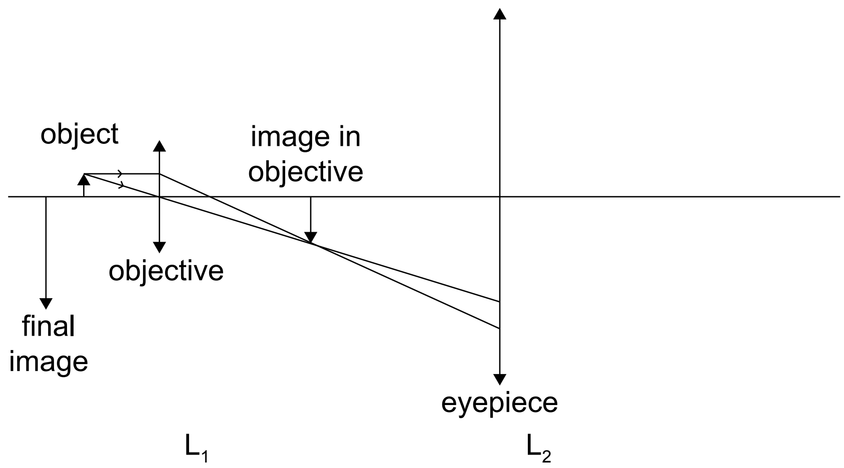
. . . .

. . . .

End of Option B

Option C — Imaging

11. (a) The diagram is a partially-completed ray diagram for a compound microscope that consists of two thin converging lenses. The objective lens L_1 has a focal length of 3.0 cm. The object is placed 4.0 cm to the left of L_1. The final virtual image is formed at the near point of the observer, a distance of 24 cm from the eyepiece lens L_2.



(i) State what is meant by a virtual image. [1]

. . . .

. . . .

(ii) Show that the image of the object formed by L_1 is 12 cm to the right of L_1. [1]

. . . .

. . . .

(iii) The distance between the lenses is 18 cm. Determine the focal length of L_2. [3]

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(Option C continues on the following page)

(Option C, question 11 continued)

(iv) On the diagram draw rays to locate the focal point of L_2. Label this point F. [2]

(b) Two converging lenses are used to make an astronomical telescope. The focal length of the objective is 85.0 cm and that of the eyepiece is 2.50 cm. The telescope is used to form a final image of the Moon at infinity.

(i) Explain why, for the final image to form at infinity, the distance between the lenses must be 87.5 cm. [2]

. . . .

. . . .

. . . .

. . . .

. . . .

(ii) The angular diameter of the Moon at the naked eye is 7.8×10^{-3} rad. Calculate the angular diameter of the final image of the Moon. [2]

. . . .

. . . .

. . . .

. . . .

(c) By reference to chromatic aberration, explain **one** advantage of a reflecting telescope over a refracting telescope. [2]

. . . .

. . . .

. . . .

. . . .

(Option C continues on the following page)

(Option C continued)

12. Communication signals are transmitted through optic fibres using infrared radiation.

(a) (i) State **two** advantages of optic fibres over coaxial cables for these transmissions. [2]

1: . . . .

. . . .

2: . . . .

. . . .

(ii) Suggest why infrared radiation rather than visible light is used in these transmissions. [1]

. . . .

. . . .

(b) A signal with an input power of 15 mW is transmitted along an optic fibre which has an attenuation per unit length of $0.30\,\text{dB}\,\text{km}^{-1}$. The power at the receiver is 2.4 mW.

Calculate the length of the fibre. [2]

. . . .

. . . .

. . . .

. . . .

(c) State and explain why it is an advantage for the core of an optic fibre to be extremely thin. [2]

. . . .

. . . .

. . . .

. . . .

(Option C continues on the following page)

(Option C continued)

13. (a) Outline why the fracture in a broken bone can be seen in a medical X-ray image. [2]

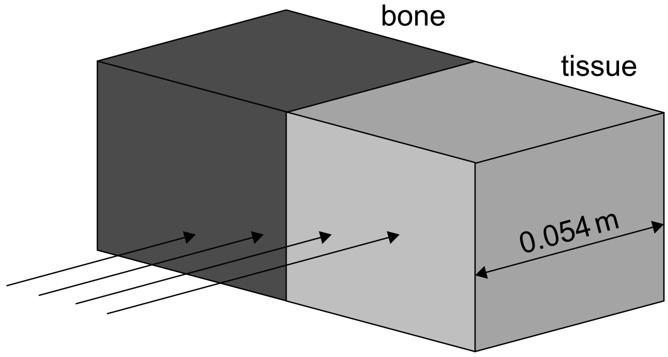
. . . .

. . . .

. . . .

. . . .

(b) The diagram shows X-rays incident on tissue and bone.



The thicknesses of bone and tissue are both 0.054 m.

The intensity of X-rays transmitted through bone is I_b and the intensity transmitted through tissue is I_t.

The following data are available.

Mass absorption coefficient for bone = mass absorption coefficient for tissue $= 1.2 \times 10^{-2}\,\text{m}^2\,\text{kg}^{-1}$
Density of bone $= 1.9 \times 10^3\,\text{kg}\,\text{m}^{-3}$
Density of tissue $= 1.1 \times 10^3\,\text{kg}\,\text{m}^{-3}$

Calculate the ratio $\frac{I_b}{I_t}$. [3]

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(Option C continues on the following page)

(Option C, question 13 continued)

(c) In the context of nuclear magnetic resonance (NMR) imaging explain the role of

(i) the large uniform magnetic field applied to the patient. [1]

. . . .

. . . .

(ii) the radio-frequency signal emitted towards the patient. [2]

. . . .

. . . .

. . . .

. . . .

(iii) the non-uniform magnetic field applied to the patient. [2]

. . . .

. . . .

. . . .

. . . .

End of Option C

Option D — Astrophysics

14. (a) Theta 1 Orionis is a main sequence star. The following data for Theta 1 Orionis are available.

Luminosity	$L = 4 \times 10^5 L_\odot$
Radius	$R = 13 R_\odot$
Apparent brightness	$b = 4 \times 10^{-11} b_\odot$

where $L_\odot$, $R_\odot$ and $b_\odot$ are the luminosity, radius and apparent brightness of the Sun.

(i) State what is meant by a main sequence star. [1]

. . . .

. . . .

(ii) Show that the mass of Theta 1 Orionis is about 40 solar masses. [1]

. . . .

. . . .

(iii) The surface temperature of the Sun is about 6000 K. Estimate the surface temperature of Theta 1 Orionis. [2]

. . . .

. . . .

. . . .

. . . .

(iv) Determine the distance of Theta 1 Orionis in AU. [2]

. . . .

. . . .

. . . .

. . . .

(Option D continues on the following page)

(Option D, question 14 continued)

(b) Discuss how Theta 1 Orionis does not collapse under its own weight. [2]

. . . .

. . . .

. . . .

. . . .

(c) The Sun and Theta 1 Orionis will eventually leave the main sequence. Compare and contrast the different stages in the evolution of the two stars. [3]

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

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

. . . .

. . . .

. . . .

. . . .

(ii) The present temperature of the CMB is 2.8 K. Calculate the peak wavelength of the CMB. [1]

. . . .

. . . .

(Option D continues on the following page)

(Option D, question 15 continued)

(b) Describe how the CMB provides evidence for the Hot Big Bang model of the universe. [2]

. . . .

. . . .

. . . .

. . . .

(c) A spectral line in the light received from a distant galaxy shows a redshift of $z = 0.16$.

(i) Determine the distance to this galaxy using a value for the Hubble constant of $H_0 = 68\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$. [2]

. . . .

. . . .

. . . .

. . . .

(ii) Estimate the size of the Universe relative to its present size when the light was emitted by the galaxy in (c). [2]

. . . .

. . . .

. . . .

. . . .

(Option D continues on the following page)

(Option D continued)

16. (a) Outline, with reference to star formation, what is meant by the Jeans criterion. [2]

. . . .

. . . .

. . . .

. . . .

(b) In the proton–proton cycle, four hydrogen nuclei fuse to produce one nucleus of helium releasing a total of 4.3×10^{-12} J of energy. The Sun will spend 10^{10} years on the main sequence. It may be assumed that during this time the Sun maintains a constant luminosity of 3.8×10^{26} W.

Show that the total mass of hydrogen that is converted into helium while the Sun is on the main sequence is 2×10^{29} kg. [2]

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(c) Massive stars that have left the main sequence have a layered structure with different chemical elements in different layers. Discuss this structure by reference to the nuclear reactions taking place in such stars. [2]

. . . .

. . . .

. . . .

. . . .

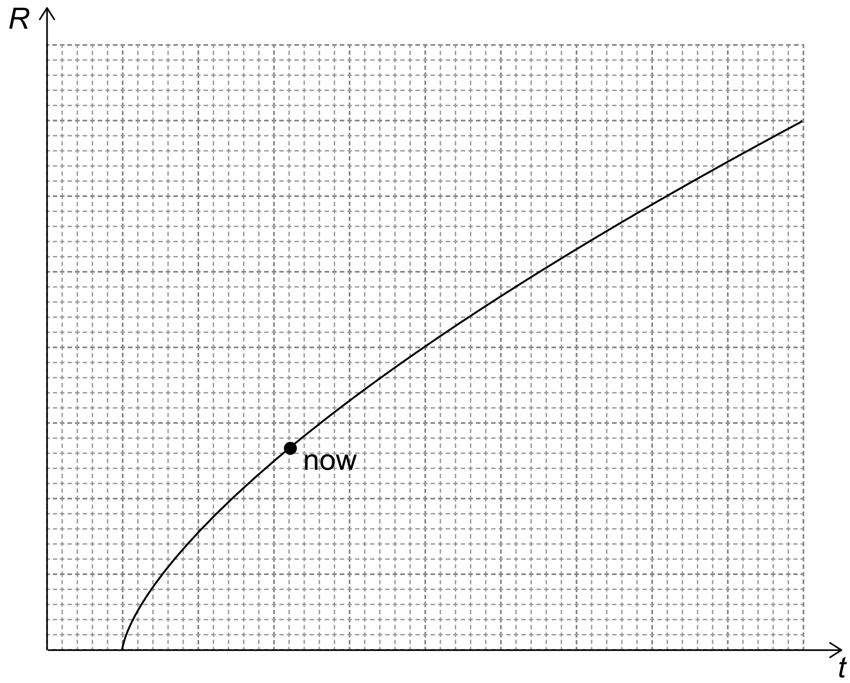
. . . .

. . . .

(Option D continues on the following page)

(Option D continued)

17. (a) The graph shows the variation with time *t* of the cosmic scale factor *R* in the flat model of the universe in which dark energy is ignored.



On the axes above draw a graph to show the variation of *R* with time, when dark energy is present. [1]

(b) Recent evidence from the Planck observatory suggests that the matter density of the universe is $\rho_m = 0.32\,\rho_c$, where $\rho_c \approx 10^{-26}\,\text{kg}\,\text{m}^{-3}$ is the critical density.

(i) The density of the observable matter in the universe is only $0.05\,\rho_c$. Suggest how the remaining $0.27\,\rho_c$ is accounted for. [1]

. . . .

. . . .

(ii) The density of dark energy is $\rho_\Lambda c^2$ where $\rho_\Lambda = \rho_c - \rho_m$. Calculate the amount of dark energy in $1\,\text{m}^3$ of space. [2]

. . . .

. . . .

. . . .

. . . .

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

Answers written on this page
will not be marked.