SPECIMEN PAPERS

SET 3

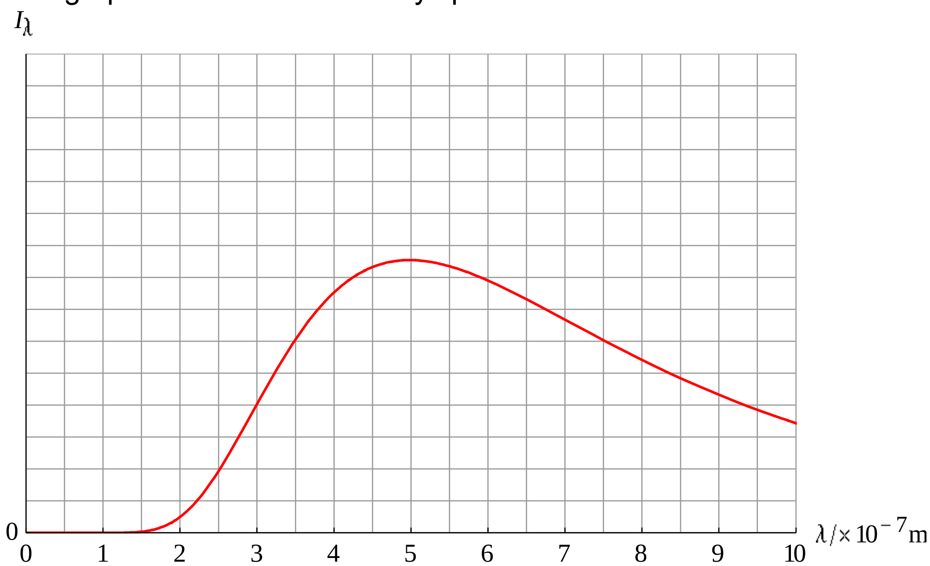
Paper 2 HL

Time allowed: 2 hours 30 minutes.

A calculator and the data booklet are required.

The total number of marks for this paper is 90.

1. The graph shows the black body spectrum of a star.



(a) Determine the surface temperature of the star. [2]

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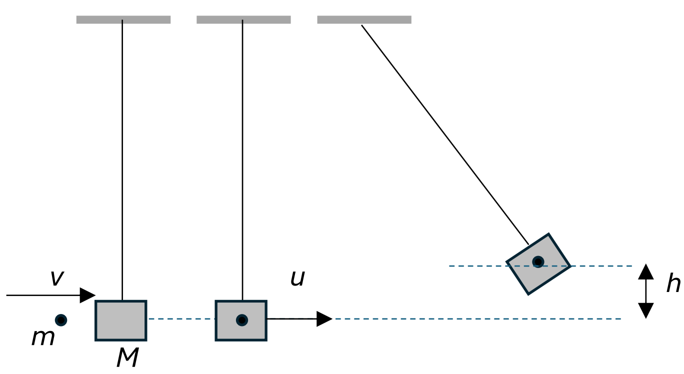
(b) On the axes draw a graph to show the black body spectrum of another star with a higher surface temperature than that of the star in (a). [1]

2. A pellet of mass *m* moving at horizontal speed *v* collides with a block of mass *M* that hangs from a vertical string. The pellet gets stuck in the block. The pellet and block move together with initial speed *u* raising their center of mass by a maximum height *h*.



The following data are available:

m = 0.025 kg

M = 1.20 kg

v = 65 m s^{-1}

(a) Calculate *u*. [2]

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(b) Determine the maximum height *h*. [2]

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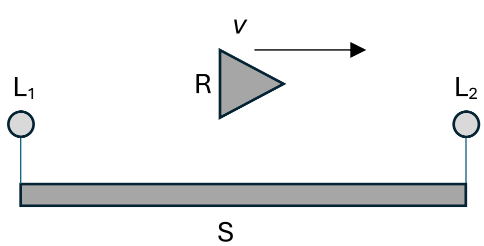
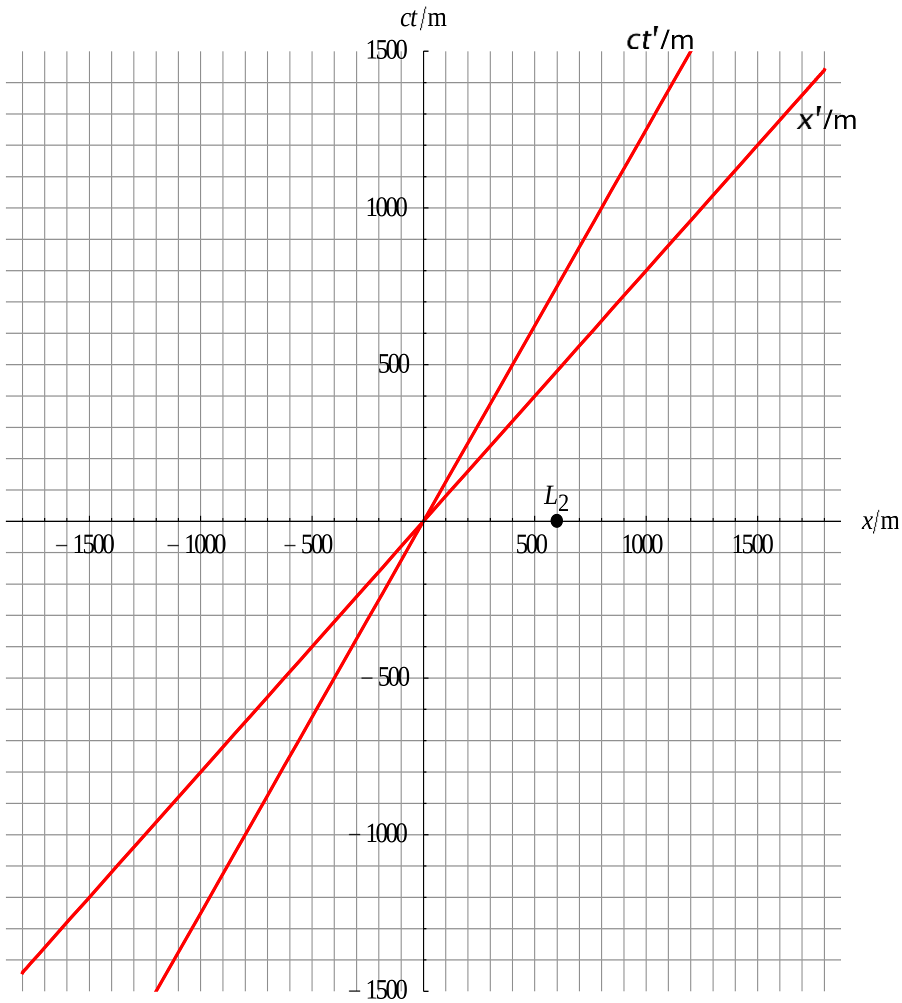
3. A rocket R moves past a space station S of proper length 1200 m at speed *v* relative to S.



(a) Two lights L_1 and L_2 at the ends of the space station turn on. According to **S,** L_1 turns on *T* seconds **before** L_2. According to R the lights turn on at the same time. The rocket was above the middle of S when L_2 turned on. The spacetime diagram shows the axes of S (x, ct) and of R (x', ct'). The event "L_2 turns on" is marked with a dot.



(i) Draw a dot to indicate the event "L_1 turns on". [2]

(ii) Determine v. [1]

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(iii) Determine T using a Lorentz transformation. [2]

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(b) Determine, using the spacetime diagram or otherwise, whether light from L_1 or L_2 reaches the rocket first. [2]

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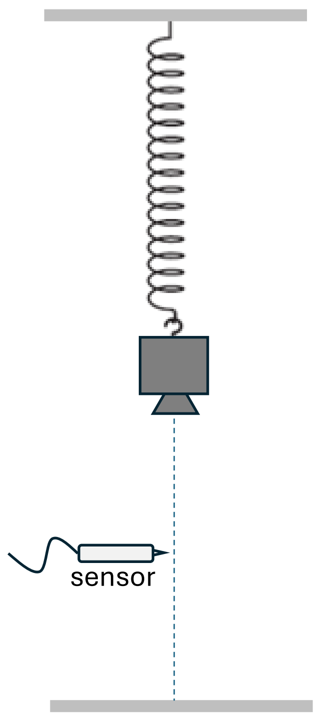
4. A speaker is attached to the end of a vertical spring. The speaker emits sound of frequency 1200 Hz towards the floor. The sound is reflected from the floor.



A sensor is moved along the dotted line.

(a) Explain why the sensor will record maxima and minima in the intensity of sound. [2]

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(b) The distance between two consecutive points where the intensity of sound is a maximum is 14 cm. Determine the speed of sound. [2]

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(c) The spring is displaced by a distance of 15.0 cm below its equilibrium position. The spring constant is 8.00×10^4 N m^{-1}. The mass of the speaker is 0.500 kg.

(i) Show that frequency of oscillations of the speaker is about 60 Hz. [1]

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(ii) Calculate the maximum speed of oscillations of the speaker. [2]

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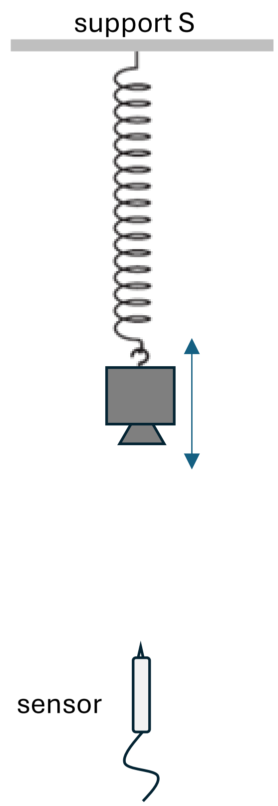
(iii) The sensor is now positioned directly below the oscillating speaker.



Calculate the range of frequencies recorded by the sensor. The speed of sound is 340 m s^{-1}. [3]

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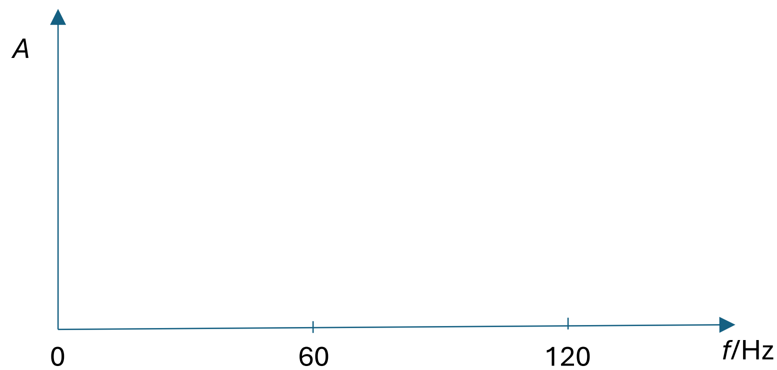
(d) The oscillations of the speaker are very lightly damped. The support S of the spring is made to oscillate with frequency *f*.

(i) Draw a graph to show the variation with driving frequency *f* of the amplitude *A* of the oscillations of the speaker. No numbers on the vertical axis are required. [3]



(ii) The driving frequency is set at the resonant frequency of the system. The sensor records the range of frequencies found in (c). The driving frequency is now decreased. State and explain what happens to the range of frequencies recorded by the sensor. [2]

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5.

(a) State what is meant by gravitational potential. [2]

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(b) The gravitational potential at the surface of a planet of radius *R* is V_0.

Determine, in terms of V_0,

(i) the work that must be done on a probe of mass *m* to bring it from the surface of the planet to a point at a height *R* from the surface. [2]

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(ii) the **additional** work to put the probe in a circular orbit at a height *R* above the surface of the planet. [1]

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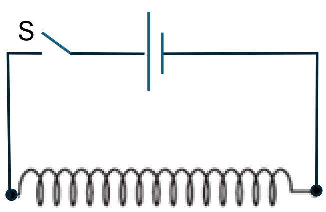
6.

(a) A flexible solenoid is connected to a cell as shown.



State and explain what, if anything, will happen to the separation of the coils of the solenoid when the switch S is closed. [2]

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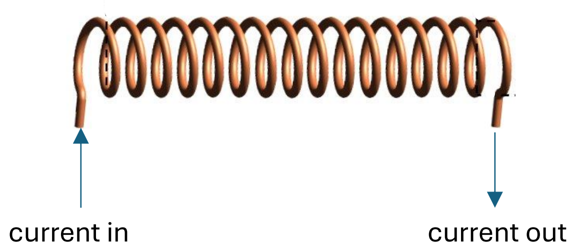
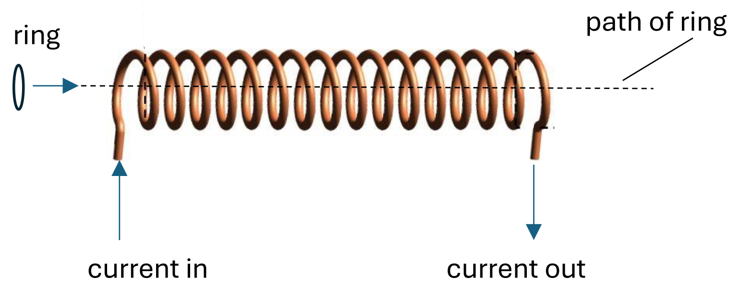
(b) Current enters a solenoid as shown. Identify with the letter N the north magnetic pole of the solenoid. [1]



(c) A ring approaches the solenoid in (b) with constant speed from the left. The ring can fit within the solenoid. The ring enters and then leaves the solenoid.

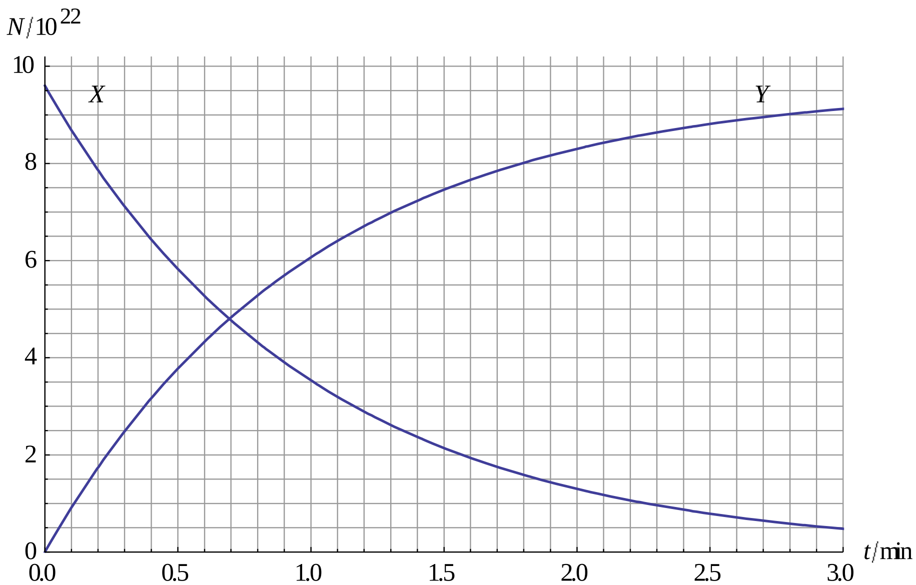


Draw graphs (no numbers required) to show the variation with time

(i) of the magnetic flux in the ring, [2]

(ii) of the magnitude of the induced emf in the ring. [2]

7. A pure radioactive sample contains 9.64×10^{22} nuclei of a nuclide X. X decays into nuclide Y. The graph shows the variation with time of the number of X and Y nuclei present in the sample.



(a) Determine the half-life of X. [1]

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(b) Suggest how it may be deduced that nuclide Y is either stable or has a very long half-life. [2]

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(c) Determine the time at which the ratio $\frac{\text{number of Y nuclei present in the sample}}{\text{number of X nuclei present in the sample}}$ is 2. [3]

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(d) The initial mass of X in the sample was 4.50 g. Estimate the nucleon number of X. [3]

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(a) The protons in a nucleus repel each other. Outline how nuclei can be stable. [2]

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(b) The nucleus of tritium ($^{3}_{1}H$) decays by beta minus decay into helium. The reaction equation is

$$^{3}_{1}H \rightarrow ^{?}_{?}He + e^{-} + ?$$

State the proton and nucleon number of the helium nucleus produced and state the name of the missing particle. [3]

Proton number:……………………………………………………………………………
Nucleon number:…………………………………………………………………………..
Missing particle:……………………………………………………………………………

(c) The following **atomic** masses are available:

Tritium	3.016049 u
Helium	3.016029 u

(i) Calculate the energy released. [2]

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(ii) State and explain whether the electron produced in the reaction in (b) has a kinetic energy equal to the energy found in (c)(i). [2]

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(d) An electron produced in the decay of tritium has kinetic energy 0.45×10^{-2} MeV. Show that the speed of this electron is about 4×10^{7} m s^{-1}. [2]

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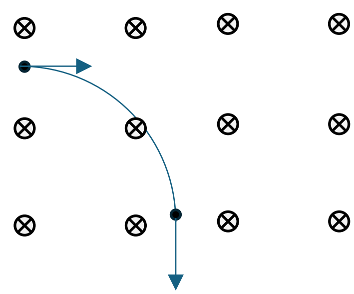
(e) The electron in (d) enters a region of uniform magnetic field 5.0 mT directed into the plane of the page. The electron's path is a quarter circle.



(i) Explain why the path of the electron is circular. [2]

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(ii) Show that the radius of the electron is given by $R = \frac{m_c v}{eB}$. [1]

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(iii) Determine the time the electron spent in the region of magnetic field. [2]

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(iv) Suggest why the speed of the electron remains constant while in the region of magnetic field. [2]

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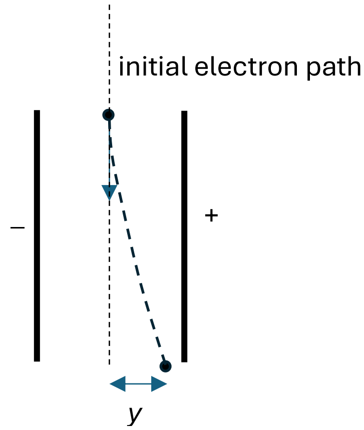
(f) The electron in (e) enters the region between two parallel oppositely charged plates after leaving the region of magnetic field. The electric field strength in between the plates is 5.8×10^{4} N C^{-1}. The time spent in between the plates is 2.2×10^{-9} s.



Determine the deviation y of the electron from its original straight-line path. [2]

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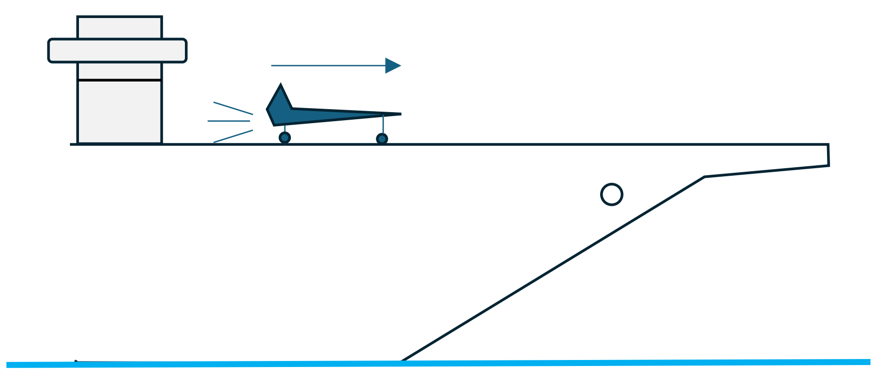
9. A plane of mass 8100 kg is taking off from an aircraft carrier. The plane accelerates uniformly from rest and reaches a takeoff speed of 82 m s^{-1} over a distance of 120 m. The plane is accelerated by a thrust engine force of 84 kN and a catapult wire force. An air resistance force of average value 55 kN acts on the plane.



(a) Calculate

(i) the time taken to take off, [1]

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(ii) the average power developed by the engine, [1]

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(iii) the force due to the catapult wire. [2]

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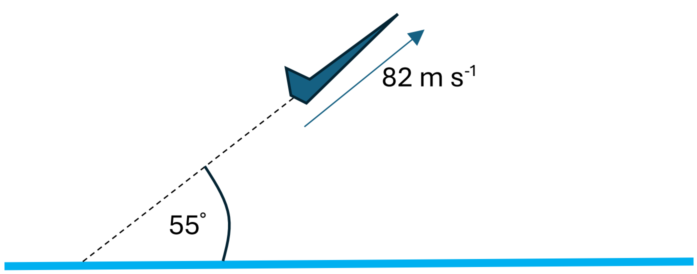
(b) After takeoff the plane is climbing at an angle of 55° to the horizontal with constant speed 82 m s^{-1}. The magnitude of the air resistance force is unchanged.



(i) State and explain whether the plane is in equilibrium. [2]

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(ii) Calculate the thrust force due to the engine. [2]

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(iii) Determine the rate of increase of the plane's gravitational potential energy. [2]

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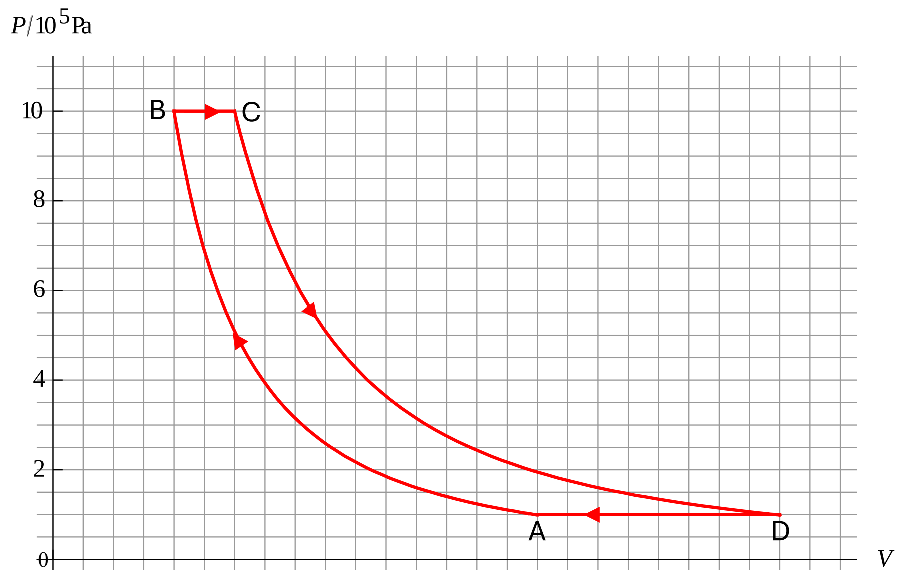
The jet engine may be modelled as a heat engine that operates on the cycle ABCDA shown on the *P*-*V* diagram. Numbers on the horizontal axis are not shown.



The cycle consists of two isobaric and two adiabatic legs.

(c) The change in volume from B to C is 0.10 m^3. Show that the thermal energy entering the engine is $2.5×10^5$ J. [3]

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(d) The thermal energy leaving the engine is $1.0×10^5$ J. Calculate the efficiency of the engine. [2]

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(e)

(i) Show that during an adiabatic process $\frac{T^5}{P^2} = \text{constant}$. [3]

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(ii) Calculate the ratio $\frac{T_A}{T_B}$ of the temperature at A to that at B. [2]

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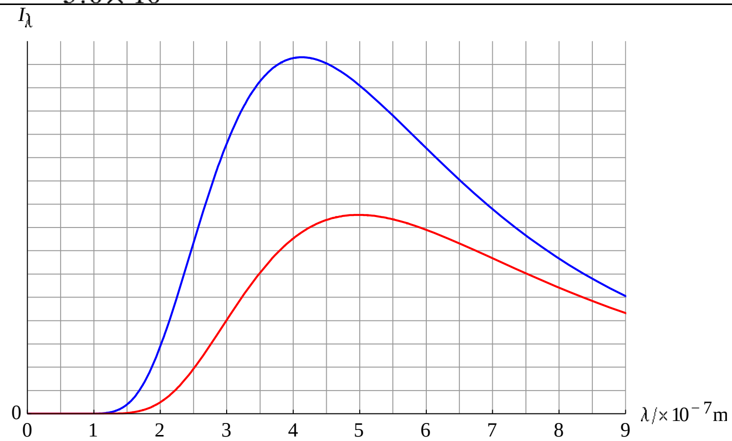
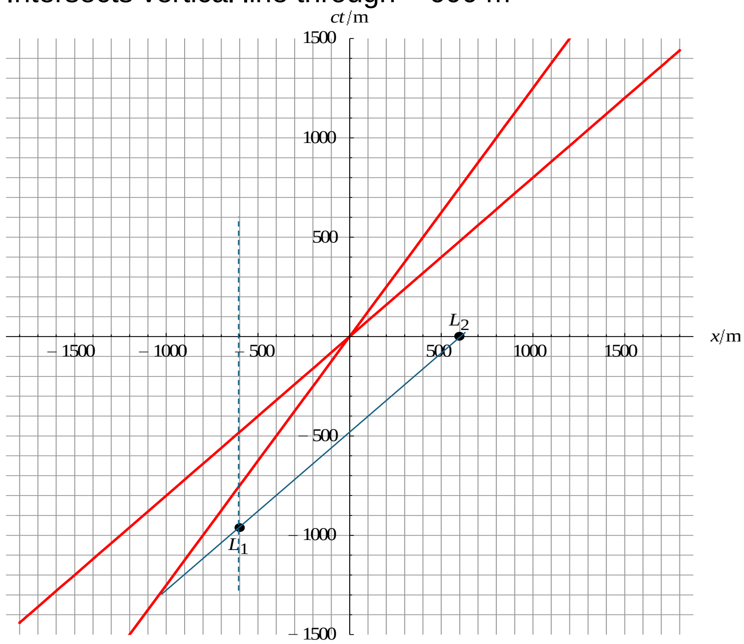
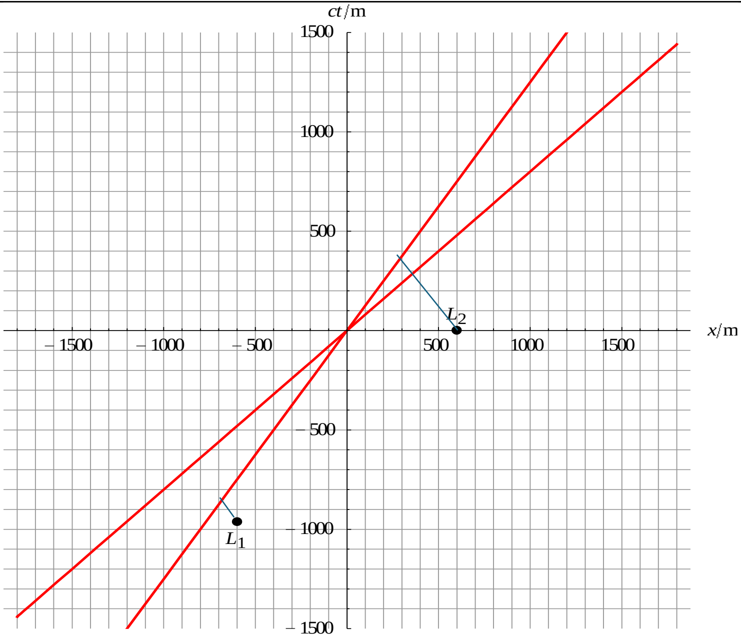
Markscheme

1				
a		Peak wavelength 5.0×10^{-7} m ✓ $T=\dfrac{2.9\times 10^{-3}}{5.0\times 10^{-7}}=5800\ \text{K}$ ✓		[2]
b		 Blue curve above red curve with peak shifted left ✓		[1]

2				
a		$mv=(m+M)u \Rightarrow u=\dfrac{mv}{m+M}$ ✓ $u=\dfrac{0.025\times 65}{0.025+1.20}=1.326\ \text{m s}^{-1}$ ✓		[2]
b		$\frac{1}{2}(m+M)u^2=(m+M)gh$ ✓ $h=\dfrac{u^2}{2g}=\dfrac{1.326^2}{2\times 9.8}=9.0\times 10^{-2}\ \text{m}$ ✓		[2]

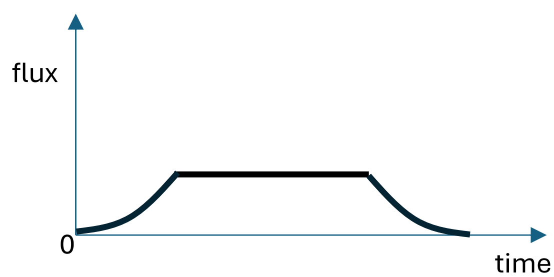
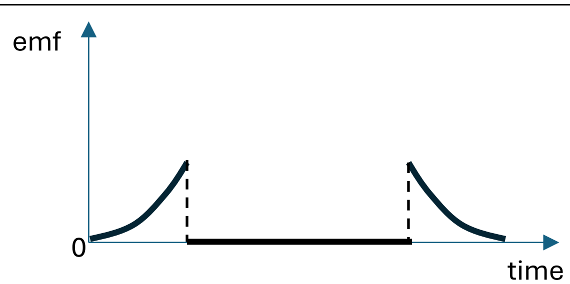
3				
a	i	Line through L_2 parallel to R space axis ✓ Intersects vertical line through – 600 m ✓  		[2]
a	ii	From spacetime diagram $v = 0.80c$ ✓		[1]
		$\Delta t' = \gamma\left(\Delta t - \frac{v}{c^2}\Delta x\right) = 0$ ✓ $\Delta t = T = \frac{v}{c^2}\Delta x = \frac{0.80}{3\times 10^8}\times 1200 = 3.2\times 10^{-6}\,\mathrm{s}$ ✓		[2]
a	iii	Photon world lines from lamps at 45° ✓ Light from L_1 intersects R time axis first ✓		[2]

4				
a		***Alternative 1*** A standing wave is set up along the dotted line because of the superposition of the incident and reflected waves✓ There will be minima at nodes and maxima at antinodes ✓ ***Alternative 2*** The incident and reflected waves interfere ✓ There will be maxima and minima at points where the phase difference is 0 or π /path difference = integer or half-integer wavelengths ✓		[2]
b		The wavelength is 28 cm ✓ Speed of sound = $1200\times 0.28 = 336 \approx 340\ \text{m s}^{-1}$ ✓		[2]
c	i	$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}} = \frac{1}{2\pi}\sqrt{\frac{8.0\times 10^4}{0.50}} = 63.7 \approx 64\ \text{Hz}$ ✓		[1]
c	ii	$\omega = 2\pi f = 2\pi \times 63.7 = 4.0\times 10^2\ \text{rad s}^{-1}$ ✓ $v_{max} = \omega A = 4.0\times 10^2 \times 0.15 = 60\ \text{m s}^{-1}$ ✓		[2]
c	iii	$f_{max} = f\frac{c}{c-v_{max}} = 1200\times\frac{340}{340-60} = 1457 \approx 1460\ \text{Hz}$ ✓ $f_{min} = f\frac{c}{c+v_{max}} = 1200\times\frac{340}{340+60} = 1020\ \text{Hz}$ ✓ Range 440 Hz ✓		[3]

d	i	Standard curve with $A \rightarrow \text{constant}$ as $f \rightarrow 0$ ✓ $A \rightarrow 0$ as $f \rightarrow \infty$ ✓ Peak at resonant frequency near 64 Hz ✓		[3]
d	ii	The maximum speed is $v_{\max} = \omega A$ so it will be reduced because both ω and A are reduced ✓ Hence the range will be reduced too ✓		[2]

5				
a		Work done <<by external agent>> per unit mass ✓ In bringing a point test mass from infinity to a point in a gravitational field <<at a constant small speed>> ✓		[2]
b	i	Potential at the given height is $V = -\frac{GM}{2R} = \frac{V_0}{2}$ ✓ $W = m\Delta V = m\left(\frac{V_0}{2} - V_0\right) = -\frac{mV_0}{2}$ ✓		[2]
b	ii	$W = \Delta E = \left(-\frac{GMm}{4R} + \frac{GMm}{2R}\right) = \frac{GMm}{4R} = -\frac{mV_0}{4}$ ✓		[1]

6				
a		The currents in adjacent coils are parallel ✓ And so will attract shortening the length of the solenoid ✓		[2]
b		N to the right ✓		[1]
c	i	 Rising and then falling outside ✓ Constant inside ✓		[2]
c	ii	 Rising and then falling outside ✓ Zero inside ✓	ECF from (i)	[2]

7				
a		0.7 min ✓		[1]
b		The sum of X and Y nuclei is constant ✓ This would be decreasing if Y was unstable with a short half-life ✓		[2]
c		$\frac{N_0 - N_0 e^{-\lambda t}}{N_0 e^{-\lambda t}} = 2 \Rightarrow e^{-\lambda t} = \frac{1}{3}$ ✓ $\lambda t = \ln 3 \Rightarrow t = \frac{\ln 3}{\lambda}$ ✓ $t = \frac{\ln 3}{\ln 2} \times 0.70 = 1.1\ \text{min}$ ✓		[3]
d		Number of moles $n = \frac{9.64 \times 10^{22}}{6.02 \times 10^{23}} = 0.160$ ✓ Mass of one mole $\frac{4.50}{0.160} = 28.1\ \text{g}$ ✓ Hence A = 28 ✓		[3]

8				
a		There is an additional force acting between protons as well as neutrons ✓ The strong nuclear force is attractive and balances the electrical force of repulsion ✓		[2]
b		Proton number: 2 ✓ Nucleon number: 3 ✓ Missing particle: antineutrino ✓		[3]
c	i	$\Delta M = (3.016049 - m_e) - (3.016029 - 2m_e) - m_e = 3.016049 - 3.01602 = 2.0 \times 10^{-5}\ \text{u}$ ✓ $Q = \Delta M c^2 = 2.0 \times 10^{-5} \times 931.5 = 1.86 \times 10^{-2}\ \text{MeV}$ ✓		[2]
c	ii	No ✓ The energy in (c)(i) is shared with the antineutrino ✓		[2]
d		$\frac{1}{2} m v^2 = E \Rightarrow v = \sqrt{\frac{2E}{m}}$ ✓ $v = \sqrt{\frac{2 \times 0.45 \times 10^{-2} \times 10^6 \times 1.6 \times 10^{-19}}{9.1 \times 10^{-31}}} = 3.978 \times 10^7\ \text{m s}^{-1}$ ✓		[2]
e	i	The initial velocity is normal to the magnetic field ✓ The magnetic force is normal to the velocity and so provides the centripetal force ✓		[2]
e	ii	$evB = m_e \frac{v^2}{R}$ ✓ Hence result		[1]
e	iii	$T = \frac{1}{4} \frac{2\pi R}{v} = \frac{1}{4} \frac{2\pi m_e}{eB}$ ✓ $T = \frac{1}{4} \frac{2\pi \times 9.1 \times 10^{-31}}{1.6 \times 10^{-19} \times 5.0 \times 10^{-3}} = 1.8\ \text{ns}$ ✓		[2]
e	iv	To change the KE and hence speed, work must be done on the electron ✓		[2]

		The work done by the magnetic force is zero since the force is at right angles to the velocity ✓		
f		$a=\frac{F}{m_e}=\frac{eE}{m_e}$ ✓ $y=\frac{1}{2}at^2=\frac{1}{2}\times\frac{1.6\times10^{-19}\times5.8\times10^4}{9.1\times10^{-31}}\times\left(2.2\times10^{-9}\right)^2=2.468\approx2.5\ \text{cm}$ ✓		[2]

9				
a	i	$s=\frac{u+v}{2}t\ \Rightarrow\ t=\frac{2s}{u+v}=\frac{2\times120}{0+82}=2.9268\approx2.9\ \text{s}$ ✓		[1]
a	ii	$\overline{P}=F\frac{u+v}{2}=\frac{84\times10^3\times82}{2}=3.4\times10^6\ \text{W}$ ✓		[1]
a	iii	$a=\frac{82}{2.9268}=28.0\ \text{m s}^{-2}$ ✓ $F+C-R=ma\Rightarrow C=ma+R-F=8100\times28.0+55\times10^3-84\times10^3=198\ \text{kN}$ ✓		[2]
b	i	Yes it is ✓ Because it travels on a straight line with constant speed/net force is zero ✓		[2]
b	ii	$F-Mg\sin\theta-R=0$ ✓ $F=Mg\sin\theta+R=8100\times9.8\times\sin55^\circ+55\times10^3=120\ \text{kN}$ ✓		[2]
b	iii	$\frac{\Delta E_g}{\Delta t}=\frac{mg\Delta h}{\Delta t}=mgv_y=mgvsin\theta$ ✓ $\frac{\Delta E_g}{\Delta t}=8100\times9.8\times82\times\sin55^\circ=5.3\times10^6\ \text{W}$ ✓		[2]
c		$\Delta U=\frac{3}{2}Rn\Delta T=\frac{3}{2}Rn\left(T_C-T_D\right)=\frac{3}{2}RnT_C-\frac{3}{2}RnT_D=\frac{3}{2}P\Delta V$ ✓ $Q=\frac{3}{2}Rn\Delta T+P\Delta V=\frac{3}{2}P\Delta V+P\Delta V=\frac{5}{2}P\Delta V$ ✓ $Q=\frac{5}{2}\times10\times10^5\times0.10=2.50\times10^5\ \text{J}$ ✓		[3]
d		$W=Q_{in}-Q_{out}=1.50\times10^5\ \text{J}$ ✓ $\eta=\frac{W}{Q_{in}}=\frac{1.5\times10^5}{2.5\times10^5}=0.60$ ✓		[2]
e	i	Combining $PV^{\frac{5}{3}}=c_1$ and $PV=RnT$ to get $P\left(\frac{RnT}{P}\right)^{\frac{5}{3}}=c_1$ ✓ $P^{-\frac{2}{3}}T^{\frac{5}{3}}=c_2$ ✓ $\left(\frac{T^5}{P^2}\right)^{\frac{1}{3}}=c_2$ raising to the third power to get result ✓		[3]

e	ii	$\frac{T_A}{T_B} = \left(\frac{P_A}{P_B}\right)^{\frac{2}{5}}$ ✓ $\frac{T_A}{T_B} = (0.10)^{\frac{2}{5}} = 0.398 \approx 0.40$ ✓		[2]