SPECIMEN PAPERS

SET 2

Paper 2 HL

Time allowed: 2 hours 30 minutes.

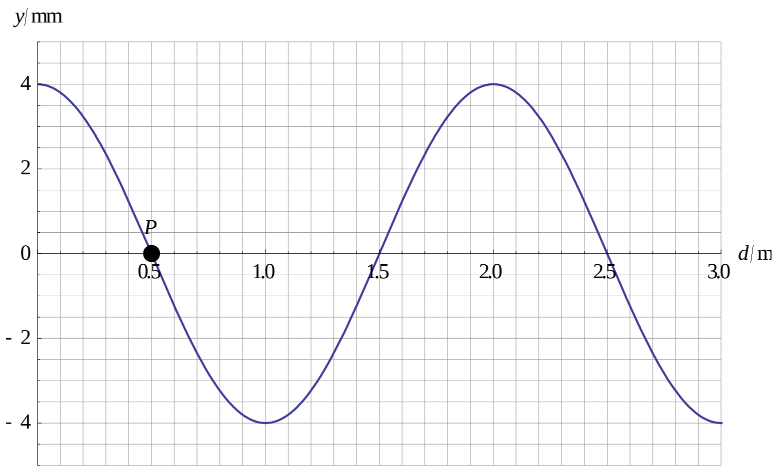
A calculator and the data booklet are required.

The total number of marks for this paper is 90.

1. [9 marks]

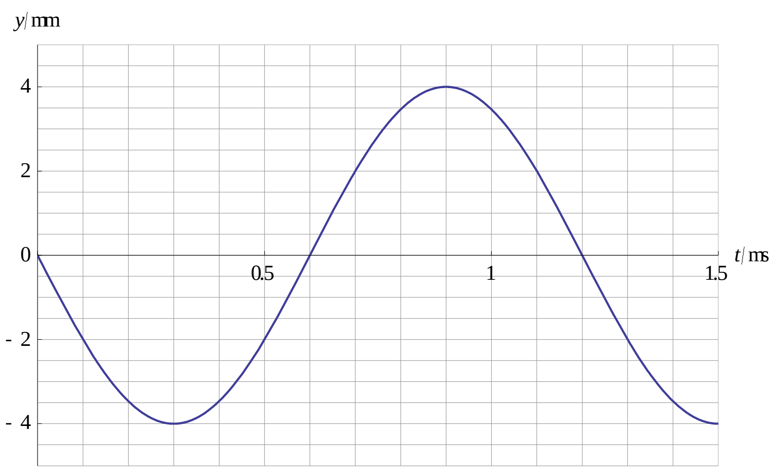
(a) State one piece of evidence that shows that travelling waves carry energy. [1]

(b) A wave travels through a medium. Graph 1 shows the variation with distance of the displacement of particles in the medium at $t = 0$. The **equilibrium** position of a particle P in the medium has been marked.



Graph 1

Graph 2 shows the variation with time of the displacement of particle P.



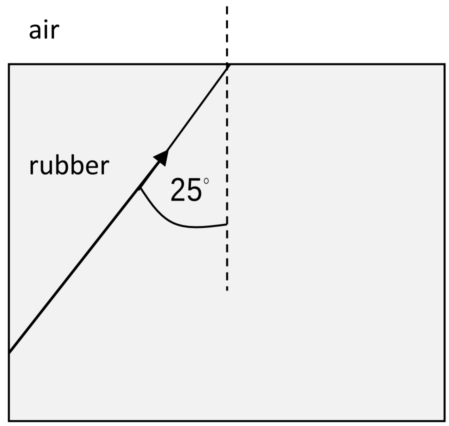
Graph 2

Determine

(i) the direction of the wave, [1]

(ii) the speed of the wave. [2]

(c) The wave in (b) is a sound wave travelling in a sheet of rubber surrounded by air. The speed of sound in air is 340 m s^{-1}.



The ray makes an angle of 25° with the normal to the sheet as shown. Determine the angle between the ray in air and the normal. [2]

(d) The wave in (c), after entering air, is directed towards the open end of a pipe whose other end is closed. Determine the minimum length of the pipe such that a standing wave is established in the pipe. [3]

2. [7 marks]

A tiny droplet of water falling though air experiences a drag force given by Stokes' law.

(a) Explain the origin of this force. [2]

(b) Determine the units of viscosity in terms of fundamental S.I. units. [1]

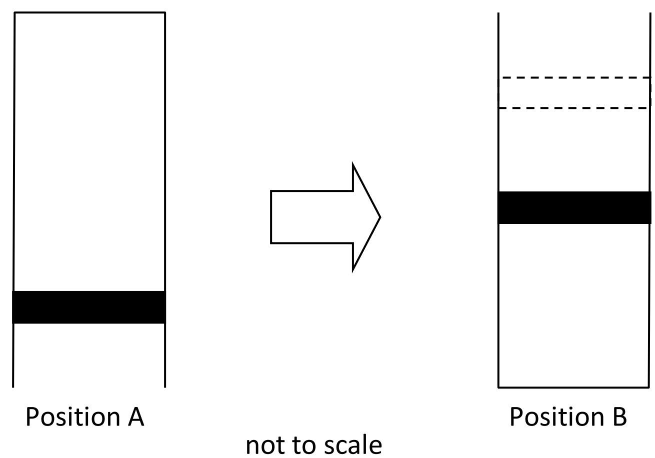
(c) The atmosphere contains tiny droplets of water of radius $5.0\times10^{-6}\text{ m}$. The density of water is 1000 kg m^{-3} and the viscosity of air in SI units is 1.8×10^{-5}. Ignore the buoyant force on the droplet.

(i) Show that the terminal speed of the droplet is $v=\frac{2\rho g}{9\eta}r^2$. [3]

(ii) Calculate this terminal speed. [1]

3. [13 marks]

(a) A tube with a cross sectional area 2.40×10^{-2} m^2 is filled with 0.500 mol of a gas at 3.00×10^{2} K. A movable piston seals the tube so the gas cannot escape. The atmospheric pressure is 1.00×10^{5} Pa. When the tube is turned upside down (position A to position B) the pressure of the gas increases by 1.50×10^{4} Pa without any change in temperature.



(i) Determine the mass of the piston. [3]

(ii) Show that the volume of the gas in position A is about 1.3×10^{-2} m^3. [2]

(iii) Show that the volume of the gas in position B is about 1.2×10^{-2} m^3. [2]

(b) With the tube in position B, the gas is heated at constant pressure, so it expands to the volume in (a)(ii). Calculate the temperature of the gas. [2]

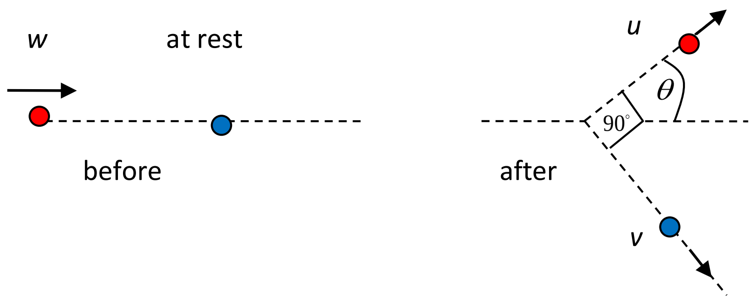
(c) For the change in (b)

(i) show that the thermal energy supplied to the gas is about 500 J, [3]

(ii) a student claims that the change in entropy of the gas is $\Delta S = \frac{Q}{T} = \frac{500}{300} = 1.67\ \text{J K}^{-1}$. Comment on this claim. [1]

4. [3 marks]

Two bodies of equal mass suffer a glancing collision. One body has speed *w* and the other is at rest. After the collision the two bodies move with speeds *u* and *v* such that the angle between them is 90°.



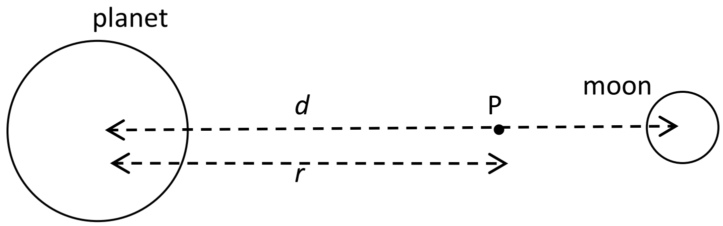
It can be shown that $u = w\cos\theta$.

(a) Show that $v = w\sin\theta$. [2]

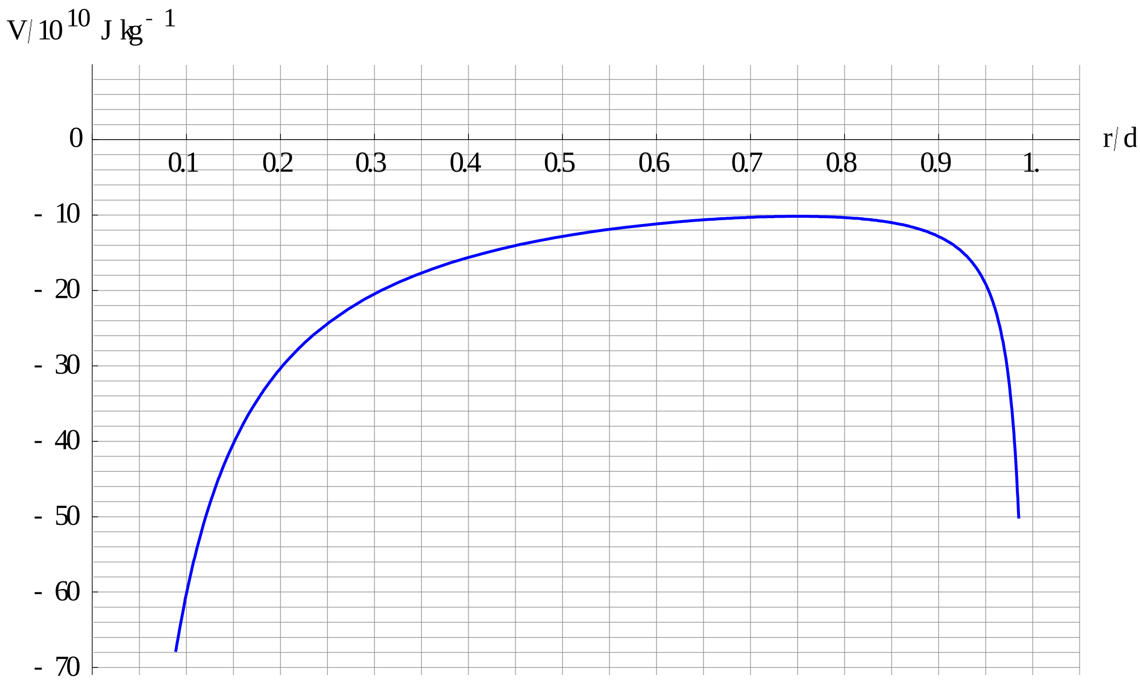
(b) Determine whether the collision is elastic. [1]

5. [6 marks]

The centres of a planet and its moon are separated by a distance *d*.



Point P is a distance *r* from the center of the planet. The graph shows the variation with *r*/*d* of the gravitational potential *V* at P. The graph starts at the surface of the planet and ends at the surface of the moon.



(a) Determine the ratio $\frac{M_{planet}}{M_{moon}}$ of the mass of the planet to the mass of the moon. [2]

(b) An amount of energy *E* is supplied to a projectile of mass 850 kg on the surface of the planet so that it reaches the surface of the moon.

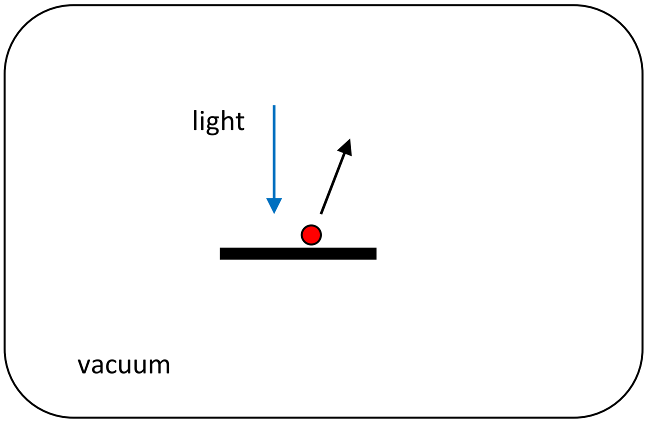
Calculate

(i) the minimum value of *E*, [2]

(ii) the speed of the projectile as it crashes on the surface of the moon when *E* has the value in (i). [2]

6. [7 marks]

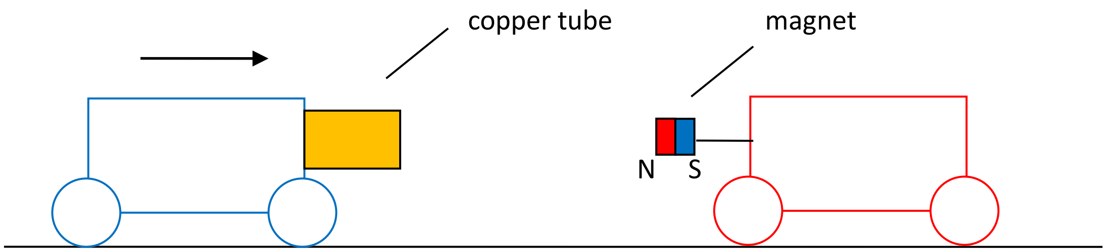
Monochromatic light of intensity 60.0 W m^{-2} is incident on a metallic surface causing the emission of electrons of kinetic energy 0.980 eV. The current that leaves the surface is 9 mA. Each photon of light has energy 1.40 eV.



(a) Show that the number of photons incident on the surface per unit time per unit area is about 1.5×10^{20}. [1]
(b) Calculate, in eV, the work function of the surface. [1]
(c) Calculate the de Broglie wavelength of the emitted electrons. [2]
(d) The intensity of the light incident on the surface is reduced to 10 W m^{-2} without a change in the wavelength. State and explain the effect of this change, if any, on
  (i) the current leaving the surface, [2]
  (ii) the answer to (c). [1]

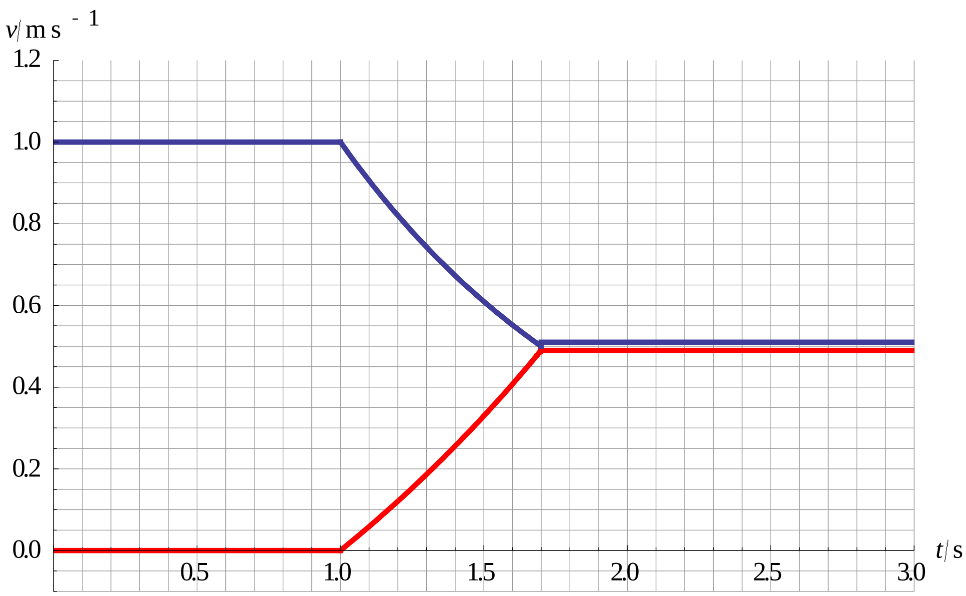
7. [5 marks]

A cart attached to a copper tube approaches a stationary cart attached to a magnet as shown. The carts never physically touch.



(a) Explain why there will be a repulsive force between the carts. [3]

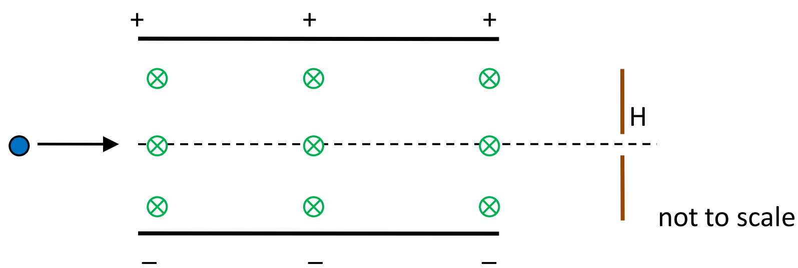
(b) The graph shows the variation with time of the speeds of the two carts.



(i) Explain why the speeds of the carts become equal. [2]

8. [20 marks]

A beam of singly ionized atoms of the same element enters the region between two parallel, oppositely charged plates in vacuum. The atoms have a range of speeds. A uniform magnetic field *B* of magnetic flux density 0.40 T is established between the plates, directed into the page. The potential difference between the plates is 2.50 kV and the plates are 8.0 mm apart. The initial direction of the beam is aligned with a small hole H beyond the plates.

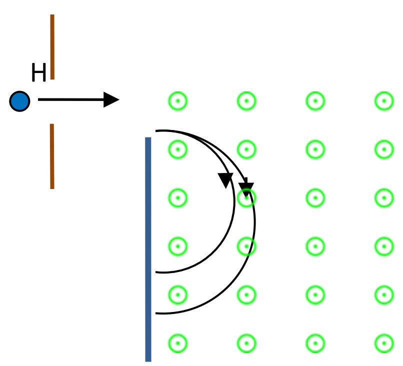


(a) (i) Determine the electric field between the plates. [1]

(ii) Explain why all the atoms that emerge through H have the same speed. [3]

(iii) Show that the common speed at H is about $7.8\times10^{5}\ \text{m s}^{-1}$. [1]

(b) The atoms in (a) that have gone through H enter a new region of magnetic field as shown. The magnetic flux density is 0.50 T and is directed out of the plane of the page.



The atoms are bent into two circular paths of different radius.

(i) Show that the radius of the circular path of charged particle in a magnetic field is given by $R=\dfrac{mv}{eB}$. [1]

(ii) State what is meant by isotopes. [2]

(iii) Outline why the presence of more than one path is evidence for isotopes. [2]

(c) The beam consists of stable atoms of neon of charge +*e*. The path of least radius corresponds to ${}^{20}_{10}\text{Ne}$.

(i) Show that this radius is about 0.3 m. [2]

(ii) Estimate the mass number of the isotope corresponding to a radius of 0.36 m. [1]

(d) ${}^{23}_{10}\text{Ne}$ is an unstable isotope of neon. ${}^{23}_{10}\text{Ne}$ decays into sodium (Na) by beta minus decay.

(i) Radioactive decay is described as random and spontaneous. State what this means. [2]

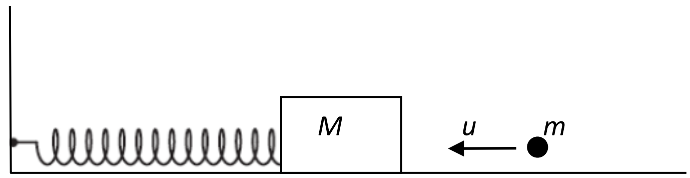
(ii) Write down the decay equation. [2]

(e) The **atomic** mass of ${}^{23}_{10}\text{Ne}$ is M_{Ne} = 22.9945 u and the **atomic** mass for Na is M_{Na} = 22.9898 u.

Determine the energy released in the decay. [3]

9. [20 marks]

A bullet of mass m and speed u is directed at a block of mass M that is attached to a spring of spring constant k. The bullet gets stuck in the block instantaneously. The block is on a frictionless table.



(a) A student suggests that the presence of the spring does not allow the use of momentum conservation for the collision of the bullet with the block. Explain why the student's reasoning is not correct. [2]

(b) Show that the speed v of the block-bullet system immediately after the collision is $v = \dfrac{mu}{M+m}$. [1]

(c)

(i) Show that the maximum compression of the spring is given by $\dfrac{mu}{\sqrt{k(m+M)}}$. [3]

The following data are available: m = 22 g, M = 5.0 kg, and k =390 N m^{-1}.

(ii) The maximum compression of the spring is 9.4 cm. Estimate the speed u of the bullet. [2]

(d) The specific heat capacity of the bullet is 320 J kg^{-1} K^{-1}. Estimate

(i) the loss of mechanical energy of the bullet. [2]

(ii) the increase in the temperature of the bullet if all the energy in (i) goes into internal energy of the bullet. [2]

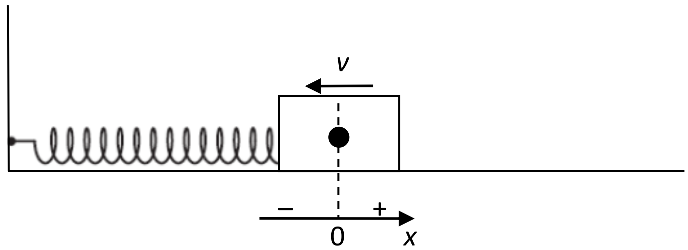
(e) The block-bullet system will perform simple harmonic oscillations after the bullet gets embedded into the block.

(i) Explain why. [1]

(ii) Determine the period of oscillations. [2]

(iii) The displacement of the block from equilibrium is given by $x = x_0 \sin(\omega t + \phi)$.

The diagram shows the position of the block-bullet system at t = 0. Positive displacements are to the right.



State the values of x_0, ω and ϕ. [3]

(iv) Determine the speed of the block when the displacement is 3.0 cm. [2]

Markscheme

		A		B		C		D		E	
		SL	AHL	SL	AHL	SL	AHL	SL	AHL	SL	AHL
Common	Q1					9					
	Q2	7									
	Q3			9	4						
	Q4		3								
	Q5								6		
	Q6										7
	Q7								5		
Common	Q8							9		11	
	Q9	10		2		3	5				
	Sub Total	17	3	11	4	12	5	9	11	11	7
	Total	20		15		17		20		18	

1				
a		The Sun warms the earth through EM waves/earthquake waves can destroy entire buildings/sound at the right frequency can shutter glass✓		[1]
b	i	According to Graph 2, the displacement after t = 0 becomes negative so the wave must be moving to the left ✓		[1]
b	ii	The wavelength is 2.0 m and the period is 1.2 ms ✓ The speed is $\frac{2.0}{1.2\times 10^{-3}} = 1.67\times 10^{3}$ m s^{-1} ✓		[2]
c		$\frac{\sin 25^{\circ}}{1.67\times 10^{3}} = \frac{\sin\theta}{340}$ ✓ $\sin\theta = \frac{340}{1.67\times 10^{3}}\times\sin 25^{\circ} = 8.604\times 10^{-2} \Rightarrow \theta = 4.9^{\circ}$ ✓		[2]
d		A standing wave can be established in the pipe if the length satisfies $\lambda = \frac{4L}{n}$ and so the minimum length is then $L = \frac{\lambda}{4}$ ✓ The wavelength in air is $\frac{1.67\times 10^{3}}{2.0} = \frac{340}{\lambda} \Rightarrow \lambda = 0.41\,\text{m}$ ✓ Hence, $L = \frac{0.41}{4} = 0.10$ m ✓		[3]

2				
a		The falling droplet exerts a force on the fluid around it making it move ✓ By Newton's third law the fluid exerts a force opposite the velocity ✓		[2]
b		$[\eta] = \frac{[F]}{[rv]} = \frac{\text{kg}\,\text{m}\,\text{s}^{-2}}{\text{m}\,\text{m}\,\text{s}^{-1}} = \text{kg}\,\text{m}^{-1}\,\text{s}^{-1}$ ✓		[1]
c	i	$mg = 6\pi\eta r v$ ✓ $\frac{4\pi}{3}r^{3}\rho g = 6\pi\eta r v$ ✓ $v = \frac{2\rho g}{9\eta}r^{2}$ ✓		[3]
c	ii	$v = \frac{2\times 1000\times 9.8}{9\times 1.8\times 10^{-5}}\times(5.0\times 10^{-5})^{2} = 3.0\times 10^{-3}\ \text{m}\,\text{s}^{-1}$ ✓		[1]

3				
a	i	At A: $P_1 + \frac{mg}{A} = P_{atm} \Rightarrow P_1 = P_{atm} - \frac{mg}{A}$ and at B: $P_2 = P_{atm} + \frac{mg}{A}$ ✓ $P_2 - P_1 = \frac{2mg}{A} = 1.50\times 10^4$ Pa ✓ $m = \frac{2.40\times 10^{-2}\times 1.50\times 10^4}{2\times 9.8} = 18.4$ kg ✓		[3]
a	ii	$P_1 = P_{atm} - \frac{mg}{A} = 1.00\times 10^5 - \frac{1.50\times 10^4}{2} = 9.25\times 10^4$ Pa ✓ $V_1 = \frac{nRT}{P_1} = \frac{0.500\times 8.31\times 300}{9.25\times 10^4} = 1.348\times 10^{-2} \approx 1.35\times 10^{-2}\text{ m}^3$ ✓		[2]
a	iii	$P_2 = P_{atm} + \frac{mg}{A} = 1.00\times 10^5 + \frac{1.50\times 10^4}{2} = 1.075\times 10^5$ Pa ✓ $P_1V_1 = P_2V_2 \Rightarrow V_2 = \frac{P_1V_1}{P_2}$ ✓ $= \frac{9.25\times 10^4}{1.075\times 10^5}\times 1.348\times 10^{-2} = 1.160\times 10^{-2} \approx 1.16\times 10^{-2}\text{ m}^3$		[2]
b		$\frac{V_2}{T_2} = \frac{V_3}{T_3} \Rightarrow T_3 = T_2\frac{V_1}{V_2}$ ✓ $T_3 = 300\times\frac{1.348\times 10^{-2}}{1.160\times 10^{-2}} = 348.6 \approx 349$ K ✓		[2]
c	i	$Q = \Delta U + W = \frac{3}{2}Rn\Delta T + P\Delta V$ ✓ $Q = \frac{3}{2}\times 0.500\times 8.31\times 48.6 + 1.075\times 10^5\times(1.348 - 1.160)\times 10^{-2}$ ✓ $Q = 505$ J ✓	Accept $Q = nc_p\Delta T$ $= \frac{5}{2}Rn\Delta T$ $= 505$ J	[3]
c	ii	The formula cannot be used because the temperature is not constant ✓		[1]

4				
a		$mu\sin\theta = mv\sin(90^\circ - \theta) = mv\cos\theta \Rightarrow v = u\frac{\sin\theta}{\cos\theta}$ ✓ $v = w\cos\theta\frac{\sin\theta}{\cos\theta} = w\sin\theta$ ✓		[2]

b		$\frac{1}{2}mu^2+\frac{1}{2}mv^2=\frac{1}{2}mw^2\cos^2\theta+\frac{1}{2}mw^2\sin^2\theta=\frac{1}{2}mw^2$ so elastic ✓		[1]

5	(a)		$\frac{GM_{\text{planet}}}{0.75^2}=\frac{GM_{\text{moon}}}{0.25^2}$ ✓ $\frac{M_{\text{planet}}}{M_{\text{moon}}}=9$ ✓		[2]
	(b)	(i)	$E=+m\Delta V=850\times(-10\times10^{10}+68\times10^{10})$ ✓ $E=4.9\times10^{14}$ J ✓		[2]
	(b)	(ii)	Energy conservation: $\frac{1}{2}mv^2-m\times50\times10^{10}=0-m\times10\times10^{10}$ ✓ ***OR*** Work-kinetic energy: $\frac{1}{2}mv^2=-m\Delta V=-m(-50\times10^{10}+10\times10^{10})$ $v=\sqrt{80\times10^{10}}=8.9\times10^5$ m s^{-1} ✓		[2]

6				
a	i	$60=Nhf\Rightarrow N=\frac{60}{1.40\times1.60\times10^{-19}}=2.678\times10^{20}\approx3\times10^{20}$ s^{-1} m^{-2} ✓		[1]
b		$0.980=1.40-\phi\Rightarrow\phi=0.420$ eV ✓		[1]
c		$0.980\times1.6\times10^{-19}=\frac{p^2}{2m_e}\Rightarrow p=5.34\times10^{-25}$ N s ✓ $\lambda=\frac{h}{p}=\frac{6.63\times10^{-34}}{5.34\times10^{-25}}=1.24\times10^{-9}$ m ✓		[2]
d	i	The number of photons is reduced ✓ So, the current is reduced ✓		[2]
d	ii	No change since electron energy does not change ✓		[1]

7				
a		As the cart approaches the magnetic flux in the copper tube increases and so an emf is induced in the tube ✓ Therefore, there is an induced current ✓ By Lenz's law, the current produces a magnetic field with the north		[3]

		pole to the right (hence force is repulsive) ✓		
b		The force becomes zero when flux no longer changes ✓ This happens when the distance between the carts is constant i.e. when the speeds of the carts are the same✓		[2]

8			
a	i	$E=\frac{V}{d}=\frac{2.5\times10^{3}}{8.0\times10^{-3}}=3.125\times10^{5}\approx3.1\times10^{5}\text{ N C}^{-1}$ ✓	[1]
a	ii	The atoms that will go through H must be undeflected ✓ So $qE=qvB$ ✓ $v=\frac{E}{B}$ i.e. speed is unique ✓	[3]
a	iii	$v=\frac{3.125\times10^{5}}{0.40}=7.813\times10^{5}\approx7.8\times10^{5}\text{ m s}^{-1}$ ✓	[1]
b	i	$qvB=\frac{mv^{2}}{R}$ hence result ✓	[1]
b	ii	Atoms of the same element/same number of protons ✓ But different number of neutrons ✓	[2]
b	iii	Different paths are due to different mass since $R=\frac{mv}{eB}$ and *v*, *q* and *B* are the same ✓ Different mass can only be due to extra neutrons since the proton number is the same /same element ✓	[2]
c	i	$R=\frac{20\times1.66\times10^{-27}\times7.813\times10^{5}}{1.6\times10^{-19}\times0.50}$ ✓ $R=0.324\approx0.3\text{ m}$ ✓	[2]
c	ii	$\frac{0.36}{0.324}\times20=22.2\approx22$ ✓	[1]
d	i	Random: it cannot be predicted which nucleus and when will decay✓ Spontaneous: the rate of decay cannot be influenced/changed✓	[2]
d	ii	${}^{23}_{10}\text{Ne}\to{}^{23}_{11}\text{Na}+e^{-}+\bar{\nu}$ Correct numbers for Na ✓ Presence of antineutrino ✓	[2]
e		$Q=\Delta mc^{2}=(\bar{M}_{\text{Ne}}-\bar{M}_{\text{Na}}-m_{e})c^{2}$ where the bar denotes **nuclear** masses ✓ $Q=(M_{\text{Ne}}-10m_{e})c^{2}-\left((M_{\text{Na}}-11m_{e})c^{2}+m_{e}c^{2}\right)=(M_{\text{Ne}}-M_{\text{Na}})c^{2}$ ✓ $Q=(22.9945-22.9898)\times931.5=4.4\text{ MeV}$ ✓ (use of MP3 alone gets [1])	[3]

9			
a		The spring does not have time to exert a force immediately after the collision ✓ So, there are no external forces and momentum is conserved ✓	[2]
b		$mu = (M+m)v \Rightarrow v = \frac{mu}{M+m}$ ✓	[1]
c	i	$\frac{1}{2}kx_0^2 = \frac{1}{2}(M+m)v^2$ ✓ $x_0 = \sqrt{\frac{(M+m)}{k}(\frac{mu}{M+m})^2}$ ✓ $x_0 = \frac{mu}{\sqrt{k(M+m)}}$ ✓ (MP3 to follow from MP2)	[3]
c	ii	$u = \frac{x_0}{m}\sqrt{k(M+m)}$ ✓ $u = 189 \approx 190 \text{ m s}^{-1}$ ✓	[2]
d	i	$\Delta E = \frac{1}{2} \times 0.022 \times 189^2 - \frac{1}{2} \times 5.022 \times (\frac{0.022}{5.022} \times 189)^2$ ✓ $\Delta E = 391 \approx 390 \text{ J}$ ✓	[2]
d	ii	$391 = 0.022 \times 320 \times \Delta T \Rightarrow \Delta T = \frac{391}{0.022 \times 320}$ ✓ $\Delta T = 56 \text{ K}$ ✓	[2]
e	i	The force from the spring on the block-bullet system is opposite and proportional to the displacement ✓	[1]
e	ii	$T = 2\pi\sqrt{\frac{M+m}{k}}$ ✓ $T = 0.71 \text{ s}$ ✓	[2]
e	iii	$x_0 = 0.094 \text{ m}$ ✓ $\omega = \frac{2\pi}{T} = \frac{2\pi}{0.71} = 8.8 \text{ s}^{-1}$ ✓ $-x_0 \sin(\omega t) = x_0 \sin(\omega t + \phi) \Rightarrow \phi = \pi$ ✓	[3]
e	iv	$v = \omega\sqrt{x_0^2 - x^2} = 8.8 \times \sqrt{0.094^2 - 0.030^2}$ ✓ $v = 0.78 \text{ m s}^{-1}$ ✓	[2]