Question	Answer	Marks	Guidance
1 (a)	In an inelastic collision, kinetic energy is not conserved	1	Momentum is conserved in all collisions, but kinetic energy is conserved only when a collision is perfectly elastic. Don't fall into the trap of saying that energy is not conserved: it must be kinetic energy that you mention.
1 (b) (i)	Momentum $p = mv$ gives $p = 0.12 \times 18 = 2.16$ N s (or kg m s^{-1})	1	Simple substitution of the given values provides the answers to these parts easily, but do remember that momentum is a vector and that its direction matters. Hitting the ball reverses its direction of travel.
1 (b) (ii)	$p = 0.12 \times (-15)$ $= -1.8$ N s (or kg m s^{-1})	1	
1 (b) (iii)	Change in momentum = 2.16 − (−1.8) = 3.96 N s (or kg m s^{-1})	1	
1 (b) (iv)	Average force $F = \frac{\Delta p}{\Delta t} = \frac{3.96}{0.14}$ = 28 N	1 1	"Force = rate of change of momentum" is the fundamental consequence of Newton's second law of motion.
1 (b) (v)	Kinetic energy lost $E_k = \frac{1}{2} \times 0.12 \times (18^2 - 15^2) = 5.9$ J	1	This confirms that the collision with the bat was inelastic. If the collision had been elastic, the speed of the ball would have been 18 m s^{-1} after impact.
2 (a)	Impulse = $F\,\Delta t$ = area under graph $= \frac{1}{2} \times 1.8 \times 0.15 = 0.135$ N s	1 1	The area to be found is that of a simple triangle of height 1.8 N and base 0.15 s. The answer could be expressed in kg m s^{-1} instead of N s. This same impulse is given to each of the carts.
2 (b)	Impulse = change of momentum $\therefore 0.135 = m_A \times 0.60$ from which $m_A = 0.225$ kg or 0.22 kg or 0.23 kg	1 1	The question states that cart A is moving at 0.60 m s^{-1} when the spring drops away. The impulse is equal to the momentum gained by each cart.
2 (c)	The final total momentum of the system is zero.	1	From the impulse, each cart receives momentum of the same magnitude. But momentum is a vector and the carts move in opposite directions. Therefore the total momentum of the system is 0.135 + (−0.135) = 0.
3 (a)	$p = mv = 6.2 \times 10^4 \times 0.35$ $= 2.17 \times 10^4$ N s (or kg m s^{-1}) or 2.2×10^4 N s	1 1	An easy two marks for showing that you know what momentum is, but a correct unit is essential for full credit.
3 (b)	Initial momentum of engine = combined momentum after coupling $\therefore 2.17 \times 10^4 = 10.2 \times 10^4\, v$ gives $v = 0.213$ m s^{-1} or 0.21 m s^{-1}	1 1 1	Momentum is conserved when the engine couples to the carriage, because the only forces acting on the system are internal forces. The mass of the combined system is (6.2 + 4.0) × 10^4 = 10.2×10^4 kg.

Question	Answer	Marks	Guidance
4 (a)	Two quantities that are conserved: • momentum • kinetic energy	2	One mark for each. Momentum is conserved in all collisions. An elastic collision (sometimes called a perfectly elastic collision) is special, because there is no loss of kinetic energy.
4 (b) (i)	Magnitude of velocity is 450 m s^{-1} The direction is away from the wall at 90 ° to it (or in the opposite direction to the initial velocity).	1 1	Since the collision is elastic, there is no loss of kinetic energy. The speed of the molecule must therefore be unchanged, but it has rebounded in the opposite direction.
4 (b) (ii)	Initial momentum $= 8.0 \times 10^{-26} \times 450$ N s (or kg m s^{-1}) final momentum $= -8.0 \times 10^{-26} \times 450$ N s (or kg m s^{-1}) change in momentum $= 7.2 \times 10^{-23}$ N s (or kg m s^{-1})	1 1	The momentum of the molecule is reversed in the collision, so its change in momentum is twice as large as it would be if the molecule were simply brought to rest.
4 (c)	Relevant points: • Force is exerted on the molecule by the wall • Molecule experiences a change in its momentum • Molecule must exert a force on the wall which is equal and opposite to the force produced by the wall on the molecule, by Newton's third law of motion	4	The change of momentum of the molecules is caused by the wall when it exerts a force on them. The question asks for an explanation of why there is a force on the wall, and requires a reference to the appropriate Newtonian law.
5 (a)	${}^{210}_{84}\mathrm{Po} \rightarrow {}^{4}_{2}\alpha + {}^{206}_{82}\mathrm{Pb}$	2	One mark for both nucleon numbers correct (4, 206) and one mark for both proton numbers correct (2, 82).
5 (b) (i)	Mass of α $= 4.0 \times 1.66 \times 10^{-27}$ $= 6.64 \times 10^{-27}$ kg E_K of α $= \frac{1}{2} \times 6.64 \times 10^{-27} \times (1.6 \times 10^{7})^2$ $= 8.50 \times 10^{-13}$ J $= \frac{8.50 \times 10^{-13}}{1.60 \times 10^{-13}} = 5.3$ MeV	1 1 1	Remember that the mass must be in kg when substituting in $\frac{1}{2} m v^2$. $1u = 1.66 \times 10^{-27}$ kg is given in the Data Booklet. Also, 1 eV $= 1.60 \times 10^{-19}$ J, so 1 MeV $= 1.6 \times 10^{-13}$ J.
5 (b) (ii)	Momentum is conserved in the explosion as the α is emitted, hence $m_{Pb}\, v_{Pb} = m_{\alpha}\, v_{\alpha}$ $206\, v_{Pb} = 4 \times 1.6 \times 10^{7}$ gives $v_{Pb} = 3.1 \times 10^{5}$ m s^{-1}	1 1 1	The only forces acting during an explosion are internal to the system, so momentum is conserved. $m_{Pb} = 206$ u and $m_{\alpha} = 4$ u. There is no need to convert these masses into kg, because the same conversion would apply to both sides of the equation.
6 (a)	The shaded area represents impulse (or change in momentum).	1	"Momentum" (without "change in") would not be an acceptable answer.

Question	Answer	Marks	Guidance
6 (b)	Initial momentum of ball = half of the shaded area $= \frac{1}{2} \times (\frac{1}{2} \times 1.6 \times 10^{-3} \times 1.7)$ $= 6.8 \times 10^{-4}$ N s (or kg m s^{-1})	1 1 1	You have to recognise that the ball will stop (and lose all its initial momentum) at the point where the force is a maximum. The area required is one half that which is shaded, rather than all of it. The area could be found by counting squares, but that would be tedious. The shape is clearly a triangle, and calculation leads to a quick result.
6 (c)	Graph to show: • Axes labelled and any line showing a reduction in negative momentum and an increase in positive momentum • Correct shape of curve	1 1	The force acting on the ball increases as it is brought to rest, so the (negative) acceleration increases. The momentum-time graph will be proportional to a velocity-time graph, where an increasing acceleration is shown by an increasing gradient. The process is reversed as the ball starts to move upwards, that is, the upwards acceleration decreases with time. Credit would be given for a graph which started with positive momentum and ended with negative momentum.
7 (a)	The total momentum of a system of objects remains constant provided that no external resultant force acts on the system	1 1	Momentum is therefore conserved in collisions and in explosions, irrespective of whether there is any change in the kinetic energy of the system. Note that it is important to include the condition…no external force….when stating this principle.
7 (b) (i)	In 1 second, volume of water entering or leaving nozzle $= \frac{\text{mass}}{\text{density}} = \frac{0.31}{1000} = 3.1 \times 10^{-4}$ m^3 speed of water $= \frac{\text{volume}}{\text{c.s. area}} = \frac{3.1 \times 10^{-4}}{7.3 \times 10^{-5}}$ $= 4.25$ m s^{-1}	1 1	It is useful to consider a time of 1 second in this kind of calculation. You can then imagine the cylinder of water that emerges from the nozzle in 1s; its length will be numerically equal to the speed of the water.
7 (b) (ii)	Change in velocity of water $= 4.25 - 0.68 = 3.57$ m s^{-1} change in momentum in 1 s $= 0.31 \times 3.57 = 1.11$ N s $F = \frac{\Delta(mv)}{\Delta t}$ gives $F = \frac{1.11}{1.0} = 1.11$ N or 1.1 N	1 1 1	This calculation is based on “force = rate of change of momentum”, which is the change in momentum in 1 s. Strictly, the answer is the force acting on the water owing to its change in momentum, but an equal and opposite force must act on the hose.

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7 (b) (iii)	The water jet produces a force on the wall, whilst a force of equal magnitude acts on the hose The force on the hose is transmitted to the Earth through its support, and this force is in the opposite direction to the force on the wall	1 1	The water jet acts like an imaginary rod, connecting the nozzle of the hose to the wall. Such a rod would produce equal and opposite pushes at its two ends, so there would be no overall effect on the rotation of the Earth.