Question			Answer	Mark	Guidance
1	(a)	(i)	$m = \frac{0.131}{6.02\times10^{23}}$ $m = 2.18\times10^{-25}$ (kg)	 A1	
		(ii)	mass of xenonejected/ s $= m_{Xe} = 2.2\times10^{-25}\times9.5\times10^{18}$ $(= 2.07\times10^{-6})$ $F_{Xe} = \left(m_{Xe}\frac{\Delta v}{\Delta t}\right) = 2.2\times10^{-25}\times9.5\times10^{18}\times3.2\times10^{4}$ $(= 0.06627)$ $a_S = \left(\frac{F_{Xe}}{m_s}\right) = \frac{2.2\times10^{-25}\times9.5\times10^{18}\times3.2\times10^{4}}{5.2\times10^{3}}$ $a_S = 1.3\times10^{-5}$ (m s^{-2})	C1 C1 A1	Possible ECF **Allow:** $5.2\times10^{3}\times\Delta v = 2.07\times10^{-6}\times3.2\times10^{4}$ $\Delta v = 1.3\times10^{-5}$ $a_S = 1.3\times10^{-5}$ (m s^{-2})
		(iii)	Rate of change of **momentum** (of an object) is proportional to the resultant / net (external) force acting upon it. (AW) **OR** statement of law of Conservation **of momentum** in a closed system/no external forces	B1	**Momentum** must be spelled correctly **Allow:** ' equal to' instead of 'proportional to' **Allow:** statement of Newton's 3rd Law provided it is clear the forces act on **different** bodies and **opposite** is spelled correctly
		(iv)	Force (on spacecraft) is constant Mass (of spacecraft) decreases (as xenon is ejected) Acceleration increases	B1 M1 A1	**Not:** Weight (of spacecraft) or 'it is lighter'
	(b)	(i)	Area under graph in range 10.5 to 11.5 (Ns) Area under graph in range 10.8 to 11.2 (Ns) $\Delta v = \frac{\text{impulse}}{m} = \frac{\text{area}}{m}$ $= \frac{11.0}{180}$ $= 6.1\times10^{-2}$ (ms^{-1})	C1 C1 C1 A1	Possible FT for using their area / 180 Use of mass of spacecraft rather than satellite scores 1 out of last 2 marks.
		(ii)	From 0 to 3 (ms) acceleration increases linearly/uniformly/ at constant rate/ at a steady rate. (From 6.5 ms) onwards/later/at end the acceleration decreases	 B1 B1	**Allow:** upper limit on time in range 3.0 to 3.5 ms Do not credit use **of 'constantly'** for this mark **Not 'decelerates'**
			Total	**14**	

<table>
<tr><th colspan="3">Question</th><th>Answer</th><th>Mark</th><th>Guidance</th></tr>
<tr><td>2</td><td>(a)</td><td></td><td>
<table>
<tr><th>Statement</th><th>Elastic collision</th><th>Inelastic collision</th></tr>
<tr><td>Total momentum for the objects is conserved.</td><td>✓</td><td>✓</td></tr>
<tr><td>Total kinetic energy of the objects is conserved.</td><td>✓</td><td></td></tr>
<tr><td>Total energy is conserved.</td><td>✓</td><td>✓</td></tr>
<tr><td>Magnitude of the impulse on each object is the same.</td><td>✓</td><td>✓</td></tr>
</table>
</td><td>B1

B1</td><td>Allow: Clear notation as alternative to tick.
Award mark only if all responses for elastic collisions are correct.
Award mark only if all responses for inelastic collisions are correct.</td></tr>
<tr><td></td><td>(b)</td><td>(i)</td><td>(Velocity) <u>increases</u> at a <u>constant</u> / <u>uniform</u> rate</td><td>B1</td><td>Allow: steady rate.
Allow: (velocity) increases with <u>constant</u> / <u>uniform</u> acceleration.
Do not allow reference to speed.</td></tr>
<tr><td></td><td></td><td>(ii)</td><td>Impulse = Area under curve
$\text{Area} = \left(\frac{1}{2}\times 0.6\times 10^{-3}\times 2.2\times 10^{3}\right)+\left(0.3\times 10^{-3}\times 2.2\times 10^{3}\right)$
$+\left(\frac{1}{2}\times 0.6\times 10^{-3}\times 2.2\times 10^{3}\right)$
$= 0.66+0.66+0.66$

$\text{Area} = 1.98$ (Ns)</td><td>C1

A1</td><td>Allow: use of trapezium formula.
Allow: counting squares.
If value is in range 780 – 800 small squares and one small square represents 2.5 x 10^{-3} (Ns) or equivalent then max of 2 marks.
If number of squares is outside this range allow max 1 mark

Allow:
Area = 2.0 (N s) but not 2 (sf error)
1 mark for Area = 2.0 x 10^{-3} omitting kN
1 mark for Area = 2000 omitting ms</td></tr>
<tr><td></td><td></td><td>(iii)</td><td>Impulse = $\Delta(mv)$
$v = \frac{1.98}{140\times 10^{-3}} = 14$ (m s^{-1})</td><td>B1</td><td>Possible ecf from b(ii)
Answer to 3 sf = 14.1 (m s^{-1}) [14.3 if using 2.0 N s]</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>6</td><td></td></tr>
</table>

Question			Answer		Marks	Guidance
3	(a)	(i)	(Resultant) force (acting on an object) is (directly) proportional to the <u>rate of change of momentum</u> (and occurs in the same direction)(AW)		B1	**Allow:** 'equal' instead of proportional, **Allow:** 'change in momentum <u>divided</u> by time taken' **Not:** a definition involving acceleration **Not:** 'change in momentum **over** time taken' **Not:** an equation unless all terms are defined
		(ii)	$F = \frac{\Delta(mv)}{\Delta t}$ $F = m\frac{\Delta(v)}{\Delta t}$ (if m is constant) $F = ma$	$F = \frac{(mv - mu)}{\Delta t}$ $F = \frac{m(v-u)}{\Delta t}$ (if m is constant) $F = ma$	M1 A1 A0	**Allow:** Any subject. **Not:** $\Delta p/\Delta t$ for M mark **Allow:** $F \propto \frac{(mv - mu)}{\Delta t}$ **Allow:** Use of t for Δt
	(b)	**(i)**	(Impulse) $F\Delta t$ = area (under graph) **OR Clear** use of ½ x 4 x 20 in $F\Delta t = m\Delta v$ $\Delta v = \frac{40}{2.5}$ $\Delta v = 16 \quad (\text{m s}^{-1})$		C1 C1 A1	**Note:** Area = 40 (N s) **Allow**: any subject
		(ii)	$a = \frac{(v-u)}{t}$ $a = \frac{16}{4}$ $a = 4.0 \quad (\text{m s}^{-2})$		B1	Possible **ecf** from **(b)(i)** **Allow:** mean force $<F>$ = 10 N mean acceleration (= $<F>/m$) = 10/2.5 = 4.0 (m s^{-2}) **Allow:** a = 4 (m s^{-2}) as answer is exact.
		(iii)	'acceleration **increases** to 2s **and** then **decreases'** Reference to the rate of change of acceleration being constant / linear change in acceleration / acceleration changes at uniform rate in either section.		M1 A1	No credit for any reference to **deceleration.** **Not:** accelerating constantly / uniform acceleration / constant acceleration / increasing rate of change of acceleration
				Total	**9**	

Question			Answer	Marks	Guidance
4	(a)	(i)	Force changes the momentum of / accelerates / decelerates the object	B1	**Allow:** Change of speed / velocity / direction <u>of motion</u>
	(b)	(i)	Force x time <u>for which the force acts</u> / <u>duration of collision</u>	B1	**Allow:** $F\,\Delta t$ with both symbols defined **Not:** change of momentum
		(ii)	Area under graph = impulse OR Area = change in momentum final velocity = Area under graph / mass	B1 B1	**Allow:** Area under graph = mv OR ... = $m(v\text{-}u)$ **Note:** v must be the subject to score this mark
	(c)	(i)	mean force on ball x time = increase in momentum of ball mean force = $\frac{0.058 \times 52}{4.2 \times 10^{-3}}$ = 720 (N)	C1 A1	Mark for correct substitution **Note:** Answer to 3 sf is 718 (N) Bald 720 (N) scores 2 marks
		(ii)	momentum change of racket = momentum (change) of ball M(38 – 32) = 0.058 x 52 $M = \frac{0.058 \times 52}{6}$ = 0.50 (kg)	C1 A1	**Allow:** use of mean force from c(i) and time 4.2ms . Possible ECF from c(i) **Note:** Answer to 3 sf is 0.503 (kg) **Allow:** 0.5 (kg)
		(iii)	The person / hand / arm holding the racket also changes momentum (AW)	B1	**Not:** references to angles or initial speed of ball
			Total	**9**	

Question			Answer	Marks	Guidance
5	(a)		Rate of change of momentum (of a body) is proportional / equal to the (net) force (acting on it) and takes place in the direction of that force.	M1 A1	**Allow:** Force = change in momentum / time (taken) ✎ **Note: momentum** must be spelled correctly to score the mark. **Allow** this mark if the M1 mark is lost for spelling error
	(b)	**(i)**	(3 x 5) – (7 x 2) = 10v v = (15 – 14)/10 = 0.10 (m s^{-1}) to the right (AW)	C1 M1 A1	Signs must be correct for the mark to be scored **Allow** 1 sf answer **Not** forwards/towards **B** but **allow** correct arrow → or east
		(ii)	Impulse = 3(0.1 – 5) (= - 14.7) = (-)15 (Ns) to the left (AW)	 M1 A1	**Allow:** ecf from (b)(i) **Ignore** sign **Not** backwards/towards **A** but **allow** correct arrow ← or west
		(iii)	(Newton's 3rd law says) Force on B (due to A) is equal and opposite to force on A (due to B) time (of contact) / t is same for both **AND** Impulse = Ft impulse on A is equal and opposite to impulse on B	 M1 A1 A0	**Allow**: use of minus sign to indicate 'opposite' **Not**: Action and reaction are equal and opposite.
			Total	**9**	