Q	Scheme	Marks	AOs	Pearson Progression Step and Progress descriptor
1a	Uses $F = ma$ to form $Ft = m(v - u)$ Explains that units for impulse of N s implies $Ft = I$ thus producing given impulse formula.	M1 A1	1.1a 2.4	3rd Derive the formulae for momentum and impulse
		(2)		
1b	Uses impulse equation to obtain, $1.2 = m_1(3 - 1)$ Gives correct answer $m_1 = 0.6$ (kg)	M1 A1	1.2 1.1b	3rd Derive the formulae for momentum and impulse
		(2)		
1c	**NB See alternative method using impulse in Notes below** Forms appropriate conservation of linear momentum equation (one side correct) Forms fully correct equation obtaining $3m_1 - m_2 = m_1 + 3m_2$ Gives correct answer $m_2 = 0.3$ (kg) Allow ft from incorrect answer to part **b**.	 M1 M1 A1ft	 3.3 1.1a 1.1b	5th Use the principle of the conservation of momentum in simple one dimensional problems
		(3)		
				(7 marks)

Notes

a **M1:** Uses $F = ma$ with suvat equation $v = u + at$ to eliminate a to form $Ft = m(v - u)$

A1: Justifies why Ft means impulse, I, either by using clear units for impulse argument or states knowledge of $I = Ft$ formula

b **M1:** Applies impulse equation with correet values substituted

A1: States correct value (accept missing units)

c **Alternative method using impulse**

M1: Forms impulse equation $1.2 = m_2(3 + 1)$ with one side correct

M1: Forms fully correct impulse equation

A1: Missing value correctly calculated

Q	Scheme	Marks	AOs	Pearson Progression Step and Progress descriptor
2a	States extension at equilibrium is 4 cm	B1	1.1b	4th
	Uses Hooke's Law to calculate upward force, $T=\frac{\lambda}{0.12}\times 0.04$	M1	3.3	Calculate the tension in a string or spring using Hooke's law
	Uses N2L to calculate downward force, $F=0.2g$ N oe	B1	1.1b	
	Thus equates to find λ, $\frac{\lambda}{0.12}\times 0.04=0.2g\Rightarrow\lambda=5.88$ **AG**	A1	1.1b	
		(4)		
2b	Defines resistance force due to friction as $F=0.2\mu g=0.14g$	M1	1.1a	5th
	Uses Hooke's Law to calculate restorative force, $R=\frac{their\ \lambda}{0.12}x$	M1	1.1b	Solve equilibrium problems involving Hooke's law in context
	Hence equates to give correct value, $x = 0.028$ m oe	A1	1.1b	
		(3)		
2c	Gives a suitable explanation E.g. friction acts to a maximum to resist the motion and so beyond this x value the restorative force would exceed the resistance force.	B1	2.4	5th Solve equilibrium problems involving Hooke's law in context
		(1)		
				(8 marks)

Notes

a Award B0M1M0A0 if equation $\frac{\lambda}{l}x=ma$ seen with no further working other than answer given.

B1: States extension as 4 cm or uses 0.04 in Hooke's Law calculation

M1: Forms an expression in λ for restorative force due to elasticity using *their* extension value

M1: Calculates force due to gravity correctly – accept $0.2g$ or AWRT 1.96

A1: Must show equating of forces before quoting given answer

b **M1:** States or uses resistance force due to friction as $0.14g$ or AWRT 1.372

M1: Forms an expression in x for restorative forec due to elasticity using *their* λ value

A1ft: States correct value for x ie AWRT 0.028 or 2.8 cm oe

c **B1:** Any explanation which correctly describes the limited nature of the force due to friction

Q	Scheme	Marks	AOs	Pearson Progression Step and Progress descriptor
3	States or uses correct equation for Power, $P = F \times v$	M1	1.2	5th
	Thus calculates driving force, $F = \dfrac{8.1\times10^6}{30} = 2.7\times10^5$ N	A1	1.1b	Use the formula for power in problem solving
	Uses N2L to model the train, *their* $F - R = 4.2 \times 10^5 \times 0.3$	M1	3.3	
	States correct value, $R = 1.4 \times 10^5$ N	A1	1.1b	
		(4)		
				(4 marks)

Notes

M1: Correct equation for power stated or used

A1: Calculates correct value for driving force (units not required)

M1: Applies N2L (must use **resultant force**) with *their* calculated driving force value

A1ft: Finds correct value AWRT 1.4×10^5 (units not required)

Q	Scheme	Marks	AOs	Pearson Progression Step and Progress descriptor
4a	Resolves vertically to slope to express maximum resistance force due to friction, $R = \mu mg\cos 30 = \frac{\sqrt{3}}{4}mg$	B1	3.3	4th Be able to include GPE when applying the work–energy principle
	Uses trigonometry and knowledge of PE formula to form, PE Lost $= mgd\sin 30 = \frac{1}{2}mgd$	M1	1.1a	
	Forms expression for KE Gained, $\frac{1}{2}m\left(v^2 - 0.1^2\right)$	M1	3.3	
	Uses work energy principle, cancelling m, to give, $\frac{\sqrt{3}}{4}gd = \frac{1}{2}gd - \frac{1}{2}\left(v^2 - \frac{1}{100}\right)$ oe	M1	3.4	
	Shows clear steps leading to given final equation.	A1	2.1	
		(5)		
4b	Substitutes v into equation to find slide length, $d = 3.04\text{ m}$	B1	1.1b	4th Be able to include GPE when applying the work–energy principle
		(1)		
4c	Assumes friction is eliminated thus states this would mean PE loss equals KE gain.	B1	2.1	5th Understand and use the principle of the conservation of mechanical energy
	Calculates KE Gained $= \frac{1}{2}m\left(5^2 - 0.1^2\right) = 12.495m$	M1	1.1b	
	Calculates PE Lost = $3.04 \times 9.8 \times m \times \sin 30 = 14.896m$	M1	1.1b	
	Energy lost, so contradiction, thus friction not eliminated	B1	2.1	
		(4)		
	(10 marks)			

Notes

a **B1:** Expresses or uses resistance force due to friction as $\mu mg\cos 30$ or $\frac{\sqrt{3}}{4}mg$ seen

M1: Expresses or uses PE Lost as $mgd\sin 30$ or $\frac{1}{2}mgd$ seen

M1: Expresses or uses KE Gained $=\frac{1}{2}m\left(v^2-0.1^2\right)$

M1: Equates *their* expressions using the work–energy principle correctly

A1: Shows how to rearrange to find the given expression. Must show at least one step between their expression and the given expression.

b **B1:** Calculates correct value by substitution including units AWRT 3.04 m

c **B1:** States basis of proof either by using conservation of mechanical energy or with reasoned use of the work–energy principle

M1: Expresses KE gained correctly in terms of *m*

M1: Expresses PE Lost correctly in terms of *m*

A1ft: Draws conclusion that energy is lost by comparison of *their* values

Q	Scheme	Marks	AOs	Pearson Progression Step and Progress descriptor
5a	Uses impulse equation in vector form to obtain, $4m\mathbf{i} - 18m\mathbf{j} = m\left(v - (2\mathbf{i} + 4\mathbf{j})\right)$	M1	1.2	4th Extend the definition of momentum and impulse to two dimensions
	Hence obtains $\boldsymbol{v} = 6\mathbf{i} - 14\mathbf{j}$	A1	1.1b	
	States clearly that $\boldsymbol{v} = 2\boldsymbol{u}_2$	M1	1.1a	
	Completes proof with clear explanation. E.g. as $\boldsymbol{v}$ is a scalar multiple of $\boldsymbol{u}_2$ then they are parallel.	A1	2.4	
		(4)		
5b	Uses conservation of linear momentum formula in vector form obtaining, $m(3\mathbf{i} - 7\mathbf{j}) + 3m(5\mathbf{i} + 8\mathbf{j}) = 4m\boldsymbol{v}$	M1	3.3	6th Use the impulse/ momentum principle in vector form
	Hence finds $\boldsymbol{v} = \frac{9}{2}\mathbf{i} + \frac{17}{4}\mathbf{j}$ oe	A1	1.1b	
	Attempts to find magnitude of *their* $\boldsymbol{v}$	M1	1.1a	
	Calculates correct speed $= \frac{\sqrt{613}}{4}\,\mathrm{m\,s^{-1}}$ AWRT 6.2 $(\mathrm{m\,s^{-1}})$	A1	1.1b	
		(4)		
				(8 marks)

Notes

a **M1:** Shows or uses Impulse equation in vector form

A1: Solves to find correct v vector (accept in column vector format)

M1: Checks to see if, or shows that, u_2 and *their* v vector are scalar multiples

A1: Uses any acceptable conclusion for proof of parallel

b **M1:** Shows or applies Conservation of linear momentum equation in vector form

A1: Solves to find correct v vector (allow column format or components given seperately clearly labelled)

M1: Uses correct method to find the magnitude of *their* v vector

A1ft: Calculates correct speed $\frac{\sqrt{613}}{4}\,\mathrm{m\,s^{-1}}$ or AWRT 6.2

Q	Scheme	Marks	AOs	Pearson Progression Step and Progress descriptor
6a	**Assuming direction of A unchanged after impact:**			5th
	Uses conservation of linear momentum to form equation for impact between A and B, giving $4mu = 7mv_B + 4mv_A$ oe	M1	3.3	Solve problems involving successive collisions of pairs of spheres in one dimension
	Uses NEL to form second equation, giving $v_B - v_A = ue$	M1	3.3	
	Solves simultaneously to form an expression for velocity of B after impact with A, giving, $v_B = \frac{4}{11}u(1+e)$	M1	1.1a	
	Uses v_B to determine the given expression for velocity of B after colliding with the wall, ω. (a step showing the expression $\omega = \frac{1}{6}e \times v_B$ must be evident)	A1	3.3	
		(4)		
6b	Determines correct expression for velocity of A after first colliding with B, $v_A = v_B - ue = \frac{1}{11}u(4-7e)$	M1	3.1b	6th
	Deduces B will also collide again with A if $\omega > -v_A$ (negative sign present dependent on direction of v_A in model).	B1	2.2a	Solve problems involving successive collisions including collisions with walls
	Thus forms quadratic inequality: $\frac{2}{33}ue(1+e) > -\frac{1}{11}u(4-7e) \Rightarrow 2e^2 - 19e + 12 > 0$	M1	1.1a	
	Hence states conditions $e < \frac{19 \pm \sqrt{265}}{4} = 0.68$ to 2dp or $e > 8.8$	A1	1.1b	
	Thus gives final answer in context $0 < e < \frac{19 \pm \sqrt{265}}{4}$ oe	A1	3.2a	
		(5)		

6c	Uses given $v_A = 0$ to state $e = \frac{4}{7}$ Uses correct formula for loss in KE = $\frac{1}{2}m\left(v_B^2 - \omega^2\right)$ Thus substitutes $e = \frac{4}{7}$ to find, KE Lost $= \frac{1}{2}mu^2\left[\left(\frac{4}{7}\right)^2 - \left(\frac{8}{147}\right)^2\right] = \frac{3496}{21609}mu^2$	**B1** **M1** **A1**	2.2a 1.2 1.1b	5th Calculate the change in kinetic energy as a result of a collision
		(3)		
				(12 marks)

Notes

Alternative: Assuming direction of *A* changed after impact,

a **M1:** Uses conservation of linear momentum to form equation, $4mu = 7mv_B - 4mv_A$

M1: Uses NEL to form second equation, $v_B + v_A = ue$

M1: As explained above

A1: As explained above

b **M1:** Uses *their* COL and NEL equations to determine an expression for v_A with alternative that if direction of *A* after impact is changed then correct expression is $v_A = \frac{1}{11}u(7e - 4)$

B1: Alternative: Deduces, by stating or using, that *B* will also collide again with *A* (if direction of *A* after first impact is changed) then $\omega > v_A$

M1: Forms quadratic using *their* v_A and given ω (allow $2e^2 - 19e + 12 = 0$ ie missing inequality)

A1ft: Solves *their* quadratic giving both roots

A1: Correct answer only

c **B1:** Correct exact *e* value only

M1: Correct method to find the KE lost in the impact.

A1: Correct solution only

Q	Scheme	Marks	AOs	Pearson Progression Step and Progress descriptor
7a	Correctly calculates EPE gained $=\frac{20}{0.5}\left(0.25^2-0.05^2\right)=2.4\,\text{J}$	B1	3.1b	6th Know the conditions for the conservation of mechanical energy with EPE included
	Correctly calculates PE Lost = $1.2\times 9.8\times 0.2 = 2.352\,\text{J}$	B1	1.1b	
	Correctly expresses KE Lost = $0.5\times 1.2\times u^2 = 0.6u^2$	M1	1.1b	
	Uses conservation of mechanical energy to form a correct expression, $2.4 = 2.352 + 0.6u^2$	M1	3.3	
	Solves to show $u = 0.2828$ **AG**	A1	1.1b	
		(5)		
7b	Calculates KE Lost = $0.6\,\text{J}$	B1	3.1b	7th Solve string/spring problems involving work and energy in familiar contexts
	Forms expression in terms of d for PE Lost = $1.2g(d-0.3)$	M1	3.3	
	Forms expression in terms of d for EPE gained $= 40((d-0.25)^2-0.05^2)$	M1	3.3	
	Uses conservation of mechnical energy and rearranges to create the quadratic, $40d^2 - 31.76d + 5.328 = 0$	M1	3.4	
	Solves and selects correct value in context $d = 0.55\,\text{m}$	A1	3.2a	
		(5)		
7ci	Uses $d = 54$ to calculate EPE gained = $3.264\,\text{J}$	B1	1.1b	7th Solve string/spring problems involving work and energy in familiar contexts
	Similarly calculates total loss in KE amd PE = $3.4224\,\text{J}$	B1	1.1b	
	Thus extra energy loss = $0.158\,\text{J}$ AWRT 0.16	A1	1.1b	
7cii	Gives valid comment. E.g. additional energy loss is likely to be due to work done against air resistance.	B1	3.5a	
		(4)		
				(14 marks)

	Notes
a	**B1:** Correct value only (units not required)
	B1: Correct value only (units not required)
	M1: Correct expression only
	M1: Uses correct method to form the conservation of mechanical energy equation with *their* values
	A1: Correct solution only
	Alternative: Using x as distance below starting position when first coming to rest
b	**B1:** Correct value for KE Lost only (units not required)
	M1: Alternative: Forms expression in terms of x for PE Lost = $1.2gx = 11.76x$
	M1: Alternative: Forms expression in terms of x for EPE gained $= 40((x + 0.05)^2 - 0.05^2)$
	M1: Uses correct method for conservation of mechanical energy to form quadratic equation **Alternative:** $40x^2 - 7.76x - 0.6 = 0$
	A1: Correct solution only AWRT 0.55 m oe (units should be given)
	Alternative: Solves and uses correct x value ($x = 0.253..$) to find d cao must be given for d
ci	**B1:** Correct value only (units not required) AWRT 3.26
	B1: Correct value only (units not required) AWRT 3.42
	A1: Correct solution only
cii	**B1:** Provides a valid comment that would account for energy loss

Q	Scheme	Marks	AOs	Pearson Progression Step and Progress descriptor
8a	Uses geometry to establish that v_Q, is inclined at $\theta°$ away from the vertical.	**B1**	2.2a	8th Solve a wide range of problems involving oblique impacts between two spheres
	Hence uses that momentum perpendicular to line of centres is unchanged to form, $u\sin\theta = v_Q\cos\theta$	**M1**	3.3	
	Uses trigonometry to deduce component of v_Q in the direction of the line of centres, $v_{Qx} = v_Q\sin\theta$	**M1**	1.1a	
	Thus states $v_{Qx} = \dfrac{u\sin^2\theta}{\cos\theta}$	**M1**	3.4	
	Uses NEL along line of centres to form $v_{Px} + v_{Qx} = 3ue\cos\theta$	**M1**	3.3	
	Uses conservation of momentum parallel to line of centres (x direction) and simplifies, $-0.2u\cos\theta = -0.5v_{Px} + 1.2v_{Qx}$	**M1**	3.3	
	Solving simultaneously to eliminate v_{Px} and substituting for v_{Qx} forms equation in terms of e, u and θ only, $\dfrac{3.4u\sin^2\theta}{\cos\theta} = 3ue\cos\theta - 0.4u\cos\theta$	**M1**	3.4	
	Thus obtains $e = \dfrac{3.4\tan^2\theta + 0.4}{3}$ so for $\tan\theta = \dfrac{1}{6}$, $e = \dfrac{89}{540}$ **AG**	**A1**	1.1b	
		(8)		
8b	Using ω for the speed of Q after impacting with wall, forms equation relating speeds parallel to the wall, $v_B\sin\theta = \omega\cos\alpha$	**M1**	3.3	7th Solve a wide range of problems involving oblique impacts with a surface
	Also uses NEL perpendicular to the wall, $\omega\sin\alpha = \dfrac{1}{5}ev_B\cos\theta$	**M1**	3.3	
	Thus shows $\tan\alpha = \dfrac{1}{5}e\cot\theta$	**A1**	1.1a	
	Hence finds $\tan\alpha = \dfrac{89}{2700} \times 6 = \dfrac{89}{450}$	**A1**	1.1b	
		(4)		
				(12 marks)

Notes

a **B1:** Use of v_Q inclined at $\theta°$ away from the vertical stated or seen.

M1: Equates momentum in direction perpendicular to the line of centres correctly (allow $v_Q \cos\delta$ ie not θ)

M1: Uses trigonometry to define x direction (line of centres) component of v_Q

M1: Combines to find correct expression for v_Q in x direction (line of centres) interms of θ (and δ)

M1: Uses correct method for NEL in x direction (along line of centres)

M1: Uses correct method for COL momentum in x direction (parallel to line of centres)

M1: Determines correct equation in terms of e, u and θ only (or just e and θ only)

A1: Shows clearly substitution of $\tan\theta = \frac{1}{6}$ to find correct exact value as given

b **M1:** Uses correct method to equate speeds in the direction parallel to the wall

M1: Uses correct method for NEL for speeds perpendicular to the wall

A1ft: Uses *their* two expressions to relate $\tan\alpha$ to e and $\tan\theta$

A1: Correct answer only