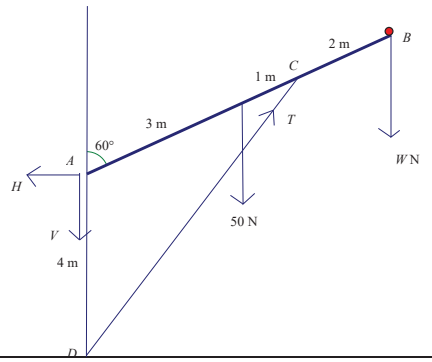
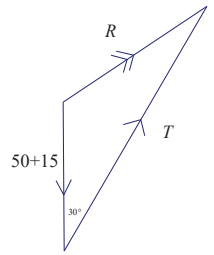
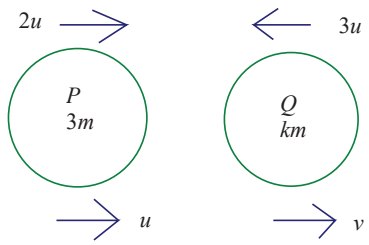
1a	Equation of motion	M1	Dimensionally correct. Condone sign error.
	$F-R=1500a$	A1	Correct unsimplified equation in F or P
	Use of $P=Fv$: $\left(\dfrac{30000}{20}-R=1500\times 0.6\right)$	M1	Must be trying to use 30 kW but condone error in zeros
	$R=600$	A1	Correct answer only
		4	
1b	Equation of motion	M1	Dimensionally correct. Need all relevant terms. Condone sign errors and sin/cos confusion. Allow with F.
	$\dfrac{30000}{V}-1500g\times\dfrac{1}{8}-500=-1500\times 0.2$	A1 A1	Unsimplified equation with F substituted and at most one error Correct unsimplified equation with F substituted. If F is never substituted, A0A0
	$V=14.7 \quad (15)$	A1	3 sf or 2 sf
		4	
		(8)	
2	1st equation e.g. Equation for change in KE	M1	Dimensionally correct. Must be subtracting but condone sign error.
	$\dfrac{1}{2}\times 0.5\left(x^2+y^2-\left(5^2+3^2\right)\right)=22$ $\left(x^2+y^2=122\right) \ \left(1^2+(2\lambda+3)^2=122\right)$	A1	Correct unsimplified equation seen or implied (They might have used impulse-momentum first and done some work before substituting x and y.)
	2nd equation e.g. Impulse-momentum equation	M1	Dimensionally correct. Must be subtracting but condone sign error.
	$0.5(x\mathbf{i}+y\mathbf{j})-0.5(5\mathbf{i}+3\mathbf{j})=(-2\mathbf{i}+\lambda\mathbf{j})$ $((x-5)\mathbf{i}+(y-3)\mathbf{j}=-4\mathbf{i}+2\lambda\mathbf{j})$	A1	Correct unsimplified equation
	NB: epen has M1A1A1 for the final 3 marks but this should be marked DM1DM1A1		
	Form a quadratic equation in λ	DM1	e.g. $1^2+(3+2\lambda)^2=122$ Dependent on the 2 preceding M marks
	Solve for 2 values of λ	DM1	e.g. solve $4\lambda^2+12\lambda-112=0$ or $(3+2\lambda)^2=121$ Dependent on the preceding M1
	$\Rightarrow \lambda=4 \quad \text{or} \quad \lambda=-7$	A1	Correct only and no errors seen (watch out for $x=-1$ used)
alt	Form a quadratic in y	DM1	e.g. $1+y^2=122 \quad (y^2=121)$ Dependent on the 2 preceding M marks
	Solve for 2 values of y and use these to obtain 2 values of λ	DM1	Dependent on the preceding M1
	$\Rightarrow \lambda=4 \quad \text{or} \quad \lambda=-7$	A1	
		7	

3a	<table><tr><td></td><td>area</td><td>distance from AE</td></tr><tr><td>rectangle</td><td>$48a^2$</td><td>$4a$</td></tr><tr><td>triangle</td><td>$18a^2$</td><td>$8a-2a\left(=6a\right)$</td></tr><tr><td>lamina</td><td>$30a^2$</td><td></td></tr></table>	B1 B1	Mass ratio correct Distances from AE (or parallel axis) correct
	M(AE)	M1	Allow use of a parallel axis. The moments equation should include a but condone if the mass ratio does not include a factor of a^2. Dimensionally correct.
	$48a^2\times4a-18a^2\times6a=30a^2\bar{x}$	A1	Correct unsimplified equation for their axis. Accept as part of a vector equation.
	$\bar{x}=\frac{84}{30}a=\frac{14}{5}a$ *	A1*	Obtain **given answer** from correct working (including correct use of a)
			If they take moments about BD they get $d=5.2a$ Allow B1B1M1A1A0 if they get this far.
		5	
3b	Find trig ratio of a relevant angle	M1	Correct use of trig.
	$\tan\theta°=\frac{3a}{2.8a}$	A1	Correct equation for the required angle. (DO NOT ISW: If they obtain 47 and then use 90 – 47 = 43 they score M1A0A0)
	$\theta=47$	A1	The Q asks for a whole number of degrees. 0.82 radians scores M1A1A0
		3	
		(8)	

4a	Use $t=2$ and $3t^2+2t=t^3+kt$ $(12+4=8+2k)$	M1	Allow verification.
	$k=4$ *	A1*	Obtain given answer from correct working. Verification requires a clear conclusion.
		2	
4b	Use of $\mathbf{a}=\frac{\mathrm{d}\mathbf{v}}{\mathrm{d}t}$	M1	Differentiate the vector **v** Majority of powers going down
	$\mathbf{a}=(6t+2)\mathbf{i}+(3t^2+4)\mathbf{j}$	A1	Correct only
	Use $\lvert\mathbf{F}\rvert=m\lvert\mathbf{a}\rvert$	DM1	Correct use of Pythagoras and N2L Dependent on the preceding M1
	$\lvert\mathbf{F}\rvert=1.5\times\sqrt{14^2+16^2}=3\sqrt{113}$	A1	Or $\frac{3}{2}\sqrt{452}$ or 32 or better (31.89….)
		4	
4c	Use of $\mathbf{r}=\int\mathbf{v}\,\mathrm{d}t$	M1	Majority of powers going up
	$\mathbf{r}=\left(t^3+t^2(+A)\right)\mathbf{i}+\left(\frac{1}{4}t^4+\frac{4}{2}t^2(+B)\right)\mathbf{j}$	A1	Allow without constant of integration
	Correct use of $\mathbf{r}=3\mathbf{i}+4\mathbf{j}$ when $t=0$ to find r when $t=2$	DM1	$\left(\mathbf{r}=\left(t^3+t^2+3\right)\mathbf{i}+\left(\frac{1}{4}t^4+\frac{4}{2}t^2+4\right)\mathbf{j}\right)$ Dependent on the preceding M1 Use of $\mathbf{r}=-3\mathbf{i}-4\mathbf{j}$ is M0
	$\mathbf{r}=15\mathbf{i}+16\mathbf{j}$	A1	Correct answer only. Accept column vector
		4	
		(10)	

5a	Use of $F_{\max} = \mu R$: $F_{\max} = \frac{2}{7} \times 1.5g\cos\theta$	M1	$(3.87...)$ Condone trig confusion. Trig substitution not required. Allow M1 if there is a clear statement for $F_{\max}$ "correct" and then used in a calculation including the gain in GPE
	Use of $\text{WD} = 2.5F_{\max}$	M1	Trig substitution not required. M0 if they have included the gain in GPE
			If the method for F is incorrect but involves the use of μ to obtain F and then they use the "work done" formula correctly allow M0M1
	$\text{WD} = 9.69 \quad (9.7)\,(\text{J})$	A1	3 sf or 2 sf not $\frac{126}{13}$
		3	
5b	Work-energy equation	M1	The Q asks for work-energy. Need all terms and dimensionally correct. Condone sign errors and sin / cos confusion
	If their answer to (a) included the GPE then it must be used for the total work done here to score the M1		
	$\frac{1}{2} \times 1.5U^2 = WD + 1.5 \times 9.8 \times 2.5 \times \sin\theta$	A1ft A1ft	Unsimplified equation with at most one error. Correct unsimplified equation Follow their WD against friction
	$U = 5.64 \quad (5.6)$	A1	3 sf or 2 sf
		4	
5c	Work-energy equation for A to A	M1	The Q asks for work-energy. Need all terms and dimensionally correct.
	$\frac{1}{2} \times 1.5v^2 = \frac{1}{2} \times 1.5U^2 - 2WD$	A1ft	Correct unsimplified equation. Follow their WD against friction and their U
	$v = 2.43\,(2.4)\,(\text{ms}^{-1})$	A1	3 sf or 2 sf
		3	
5c alt	Work-energy equation for B to A	M1	The Q asks for work-energy. Need all terms and dimensionally correct.
	$\frac{1}{2} \times 1.5v^2 = 1.5 \times 9.8 \times 2.5 \times \sin\theta - WD$	A1ft	Correct unsimplified equation. Follow their WD
	$v = 2.43\,(2.4)\,(\text{ms}^{-1})$	A1	3 sf or 2 sf
		3	
		(10)	

6a			
	M(A)	M1	Or equivalent method to form an equation in W only. Equation(s) must be dimensionally correct and contain all relevant terms. Condone sin / cos confusion and sign error(s)
	$50\times3\cos30°+W\times6\cos30°=60\sqrt{3}\times4\sin30°$	A1 A1	Unsimplified equation with at most one error. Correct unsimplified equation
	$W=15$ *	A1*	Correct answer only
		4	
6b	First equation e.g. Resolve vertically	M1	Or resolve parallel to pole
	$(\pm)V+50+15=T\cos30°\quad(V=25)$	A1	Or: $P+50\cos60°+15\cos60°=60\sqrt{3}\times\dfrac{\sqrt{3}}{2}$
	Second equation e.g. Resolve horizontally	M1	Or resolve perpendicular to the pole
	$(\pm)H=T\cos60°\left(=30\sqrt{3}=51.96.....\right)$	A1	Or: $50\cos30°+15\cos30°=60\sqrt{3}\cos60°+Q$
	NB: One of the equations could be a second moments equation		
	$\lvert R\rvert=\sqrt{25^2+\left(30\sqrt{3}\right)^2}$	DM 1	Dependent on the 2 preceding M marks $\left(\sqrt{57.5^2+3\times6.25}\right)$
	$=5\sqrt{133}\left(57.662.....\right)$ (N)	A1	58 N or better
		6	Full marks available using $\pm V,\pm H,\pm P,\pm Q$
6b alt	Form vector triangle for the vertical forces, the thrust and the resultant Correct triangle	M1 A1	
	Use cosine rule	M1	
	$R^2=T^2+\left(50+W\right)^2-2T\left(50+W\right)\cos30°$	A1	Correct unsimplified equation
	$R^2=\left(60\sqrt{3}\right)^2+\left(65\right)^2-2\times60\sqrt{3}\times65\cos30°$	DM 1	Substitute values and solve for $\lvert R\rvert$
	$\lvert R\rvert=5\sqrt{133}\left(57.662.....\right)$ (N)	A1	58 N or better
		6	
		(10)	

7a			
	Use CLM	M1	Need all terms and dimensionally correct. Condone sign errors. Might see them using equal (and opposite) impulses.
	$6mu - 3kmu = 3mu + kmv \quad \left((3-3k)u = kv\right)$	A1	Correct unsimplified equation
	$\Rightarrow v = \dfrac{(3-3k)}{k}u \quad *$	A1*	Obtain **given answer** from full and correct working
		3	
7b	Use of Impulse = change in momentum	M1	Must be subtracting. Can be for either particle.
	$\lvert I_Q\rvert = \lvert I_P\rvert = \lvert 3mu - 3m.2u\rvert = 3mu$ or $\lvert kmv - (-3mku)\rvert = \left\lvert km.\dfrac{3-3k}{k}u + 3mku\right\rvert = 3mu$	A1	Correct only (Do not need to state that $\lvert I_Q\rvert = \lvert I_P\rvert$ if find $\lvert I_P\rvert$)
		2	
7c	Use impact law:	M1	Seen or implied. If stated in (a) must be used here. Must be used correctly but condone sign errors
	$\dfrac{v-u}{5u} = e$ or $\dfrac{3-3k}{k}u - u = 5ue$	A1	Correct unsimplified equation
	NB: the second and third M mark are not dependent on the first M mark		
	Use $v > u$ or $e > 0$ to form an inequality in k	M1	Could use $e \ldots 0$ followed by $v \neq u$
	Use $e \geqslant 1$ to form an inequality in k	M1	
	$\dfrac{3-3k}{k} > 1$ and $3-3k \geqslant 6k \quad \Rightarrow \dfrac{1}{3} \geqslant k < \dfrac{3}{4}$	A1	Correct answer only.
		5	
		(10)	

8a	Condone use of θ or a mixture of θ and α throughout but final answer should be in one variable.		
	Equation for horizontal distance	M1	Complete method using *suvat.* Condone sine / cosine confusion
	$x = u\cos\alpha\, t$	A1	Correct only
	Equation for vertical distance	M1	Complete method using *suvat.* Condone sine / cosine confusion and sign error
	$y = u\sin\alpha\, t - \frac{1}{2}gt^2$	A1	Correct only
	$t = \frac{x}{u\cos\alpha} \Rightarrow$ $y = u\sin\alpha.\frac{x}{u\cos\alpha} - \frac{g}{2}\left(\frac{x}{u\cos\alpha}\right)^2$	DM1	Substitute for t to obtain y in terms of x and α Dependent on the 2 preceding M marks
	$\Rightarrow y = x\tan\alpha - \frac{gx^2}{2u^2}\left(1+\tan^2\alpha\right)$ *	A1*	Obtain **given answer** from full and correct working. Need some evidence for the final step. $\frac{1}{\cos^2\alpha} = 1+\tan^2\alpha$ is not sufficient.
		6	
8b	Conservation of energy:	M1	Method specified in the question. Need all terms and dimensionally correct. Condone sign errors
	$\frac{1}{2}m\times 25^2 = \frac{1}{2}mU^2 + mg\times 20$	A1	Correct unsimplified equation
	$U = 15.3\ \ (15)$	A1	3 sf or 2 sf only
		3	
8c	Use part (a) or work from first principles to form an equation in $\tan\theta$	M1	$\left(-20 = 30\tan\theta - \frac{9.8\times 900}{2U^2}\left(1+\tan^2\theta\right)\right)$
	Obtain $18.9\tan^2\theta - 30\tan\theta - 1.07 = 0$ $\left(\frac{4410}{233}\tan^2\theta - 30\tan\theta - \frac{250}{233} = 0\right)$	A1ft	Or 3 term equivalent Follow their U Can be implied by a correct final answer
	$\Rightarrow \theta = 58.3°$ or $58°$	A1	3 sf or 2 sf only
		3	
		(12)	