1(i)	$(-\mathbf{i}+16\mathbf{j}+72\mathbf{k})+(-80\mathbf{k})=8\mathbf{a}$ $\mathbf{a}=\left(-\frac{1}{8}\mathbf{i}+2\mathbf{j}-\mathbf{k}\right)\text{m s}^{-2}$	M1 E1	Use of N2L. All forces present. Need at least the **k** term clearly derived	2
(ii)	$\mathbf{r}=4(\mathbf{i}-4\mathbf{j}+3\mathbf{k})+0.5\times16\left(-\frac{1}{8}\mathbf{i}+2\mathbf{j}-\mathbf{k}\right)$ $= 3\mathbf{i} + 4\mathbf{k}$	M1 A1 A1	Use of appropriate **uvas*t*** or integration (twice) Correct substitution (or limits if integrated)	3
(iii)	$\sqrt{3^2+4^2}=5$ so 5 m	B1	FT **their** (ii) even if it not a displacement. Allow surd form	1
(iv)	$\arctan\frac{4}{3}$ $= 53.130\ldots$ so 53.1° (3 s. f.)	M1 A1	Accept $\arctan\frac{3}{4}$. FT **their** (ii) even if not a displacement. Condone sign errors. (May use arcsin4/5 or equivalent. FT **their** (ii) and (iii) even if not displacement. Condone sign errors) cao	2
				8

2		mark		Sub
(i)	**either**			
	Need **j** cpt 0 so $18t^2 - 1 = 0$	M1	Need not solve	
	$\Rightarrow t^2 = \frac{1}{18}$. Only one root as $t > 0$	E1	Must establish only one of the two roots is valid	
	or			
	Establish sign change in **j** cpt	B1		
	Establish only one root	B1		
				2
(ii)	$\mathbf{v} = 3\,\mathbf{i} + 36t\,\mathbf{j}$	M1 A1	Differentiate. Allow **i** or **j** omitted	
	Need **i** cpt 0 and this never happens	E1	Clear explanation. Accept '**i** cpt always there' or equiv	
				3
(iii)	$x = 3t$ and $y = 18t^2 - 1$	B1	Award for these two expressions seen.	
	Eliminate t to give			
	$y = 18\left(\frac{x}{3}\right)^2 - 1$	M1	t properly eliminated. Accept any form and brackets missing	
	so $y = 2x^2 - 1$	**A1**	ca	
				3
				8

3	**(i)**		$\mathbf{v} = \mathbf{u} + \mathbf{a}t$	M1	May be implied by either of the next two answers but not the final answer. Evidence of use of vectors in question necessary.
			Velocity $\mathbf{v} = \begin{pmatrix} 2 \\ 0 \end{pmatrix} + t\begin{pmatrix} -1 \\ 1 \end{pmatrix}$ $\left(= \begin{pmatrix} 2-t \\ t \end{pmatrix}\right)$	A1	
			When $t = 8$, $\mathbf{v} = \begin{pmatrix} -6 \\ 8 \end{pmatrix}$	A1	May be implied by the final answer
			speed $\sqrt{(-6)^2 + 8^2} = 10$ m s^{-1}	A1	Cao but condone no units Give SC2 for 10 without working
				[4]	
	(ii)		$\mathbf{r} = \mathbf{r}_0 + \mathbf{u}t + \frac{1}{2}\mathbf{a}t^2$	M1	Use of correct equation with substitution. Condone omission of $\mathbf{r}_0$ Or equivalent equation
			$\mathbf{r} = \begin{pmatrix} 0 \\ -2 \end{pmatrix} + \begin{pmatrix} 2 \\ 0 \end{pmatrix} \times 8 + \frac{1}{2} \times \begin{pmatrix} -1 \\ 1 \end{pmatrix} \times 8^2$	A1	Condone omission of $\mathbf{r}_0$. Follow through for their value of $\mathbf{v}$
			$\mathbf{r} = \begin{pmatrix} -16 \\ 30 \end{pmatrix}$	A1	Cao but may be implied by a correct final answer.
			Distance = 34 m	A1	Allow for 35.77... from $\mathbf{r} = \begin{pmatrix} -16 \\ 32 \end{pmatrix}$ and 37.57... from $\mathbf{r} = \begin{pmatrix} -16 \\ 34 \end{pmatrix}$
				[4]	

4		mark	notes
(i)	When $t = 1$, $\mathbf{r} = \begin{pmatrix} 8 \\ 10-2 \end{pmatrix} = \begin{pmatrix} 8 \\ 8 \end{pmatrix}$ $[8\mathbf{i} + (10-2)\mathbf{j} = 8\mathbf{i} + 8\mathbf{j}]$ Bearing OP is 045°	B1 F1 2	Accept column or $a\mathbf{i} + b\mathbf{j}$ notation May be implied Accept 45°. Accept NE and northeast. Condone $\lvert\mathbf{r}\rvert$ given as well.
(ii)	$\mathbf{v} = \begin{pmatrix} 8 \\ 20t - 6t^2 \end{pmatrix}$ $[8\mathbf{i} + (20t - 6t^2)\mathbf{j}]$ The **i** cpt is always 8 so $\mathbf{v} \neq \mathbf{0}$ for any t	M1 A1 E1 3	Differentiating both components. Condone 1 error if clearly attempting differentiation. Must be a vector answer. Accept any correct argument e.g. based on **i** cpt never 0.
(iii)	$\mathbf{a} = \begin{pmatrix} 0 \\ 20-12t \end{pmatrix}$ $[(20 - 12t)\mathbf{j}]$ $\mathbf{a} = \mathbf{0}$ when $t = \frac{20}{12} = \frac{5}{3}$ so $\frac{5}{3}$ s (1.67 s (3 s. f.))	M1 F1 B1 3	Differentiating as a vector. Condone 1 error if clearly attempting differentiation of **their v**. FT **their v**. cao. Condone obtained from scalar equation.
		8	

				5
5 (i)	$\begin{pmatrix}12\\9\end{pmatrix}=\begin{pmatrix}2\\-3\end{pmatrix}+4\mathbf{a}$ so **a** = $\begin{pmatrix}2.5\\3\end{pmatrix}$	**M1** A1	Us of $\mathbf{v}=\mathbf{u}+\mathbf{a}t$ If vector **a** seen, isw.	2
(ii)	**eit** $\mathbf{r}=\begin{pmatrix}-1\\2\end{pmatrix}+\begin{pmatrix}2\\-3\end{pmatrix}\times 4+\frac{1}{2}\mathbf{a}\times 4^2$ $\mathbf{r}=\begin{pmatrix}27\\14\end{pmatrix}$ so $\begin{pmatrix}27\\14\end{pmatrix}$ m **or**	M1 A1 A1 M1 A1 A1	For use of $\mathbf{s}=\mathbf{u}t+\frac{1}{2}\mathbf{a}t^2$ with **their a.** Initial position may be omitted. FT **their a.** Initial position may be omitted. cao. Do not condone magnitude as final answer. Use of $\mathbf{s}=0.5t(\mathbf{u}+\mathbf{v})$ Initial position may be omitted. Correct substitution. Initial position may be omitted. cao Do not condone mag as final answer. SC2 for $\begin{pmatrix}28\\12\end{pmatrix}$	3
(iii)	Using N2L **F** = 5**a** = $\begin{pmatrix}12.5\\15\end{pmatrix}$ so $\begin{pmatrix}12.5\\15\end{pmatrix}$ N	M1 F1	Use of **F** = *m***a** or **F** = *mg***a**. FT **their a** only. Do not accept magnitude as final ans.	2
				7

6		Mark	Comment	Sub
(i)	$v_x = 8 - 4t$ $v_x = 0 \Leftrightarrow t = 2$ so at $t = 2$	M1 A1 F1	**either** Differentiating **or** Finding '*u*' and '*a*' from *x* and use of $v = u + at$ FT **their** $v_x = 0$	3
(ii)	$y = \int (3t^2 - 8t + 4)\, dt$ $= t^3 - 4t^2 + 4t + c$ $y = 3$ when $t = 1$ so $3 = 1 - 4 + 4 + c$ so $c = 3 - 1 = 2$ and $y = t^3 - 4t^2 + 4t + 2$	M1 A1 **M1** E1	Integrating v_y with at least one correct integrated term. All correct. Accept no arbitrary constant. Clea evidence Clearly shown and stated	4
(iii)	We need $x = 0$ so $8t - 2t^2 = 0$ so $t = 0$ or $t = 4$ $t = 0$ gives $y = 2$ so 2 m $t = 4$ gives $y = 4^3 - 4^3 + 16 + 2 = 18$ so 18 m	M1 A1 A1 A1	May be implied. Must have both Condone 2**j** Condone 18**j**	4
(iv)	We need $v_x = v_y = 0$ From above, $v_x = 0$ only when $t = 2$ so evaluate $v_y(2)$ $v_y(2) = 0$ [$(t - 2)$ is a factor] so yes only at $t = 2$ At $t = 2$, the position is (8, 2) Distance is $\sqrt{8^2 + 2^2} = \sqrt{68}$ m (8.25 3 s.f.)	M1 M1 A1 B1 B1	**either** Recognises $v_x = 0$ when $t = 2$ **or** Finds time(s) when $v_y = 0$ **or** States or implies $v_x = v_y = 0$ Considers $v_x = 0$ **and** $v_y = 0$ with **their** time(s) $t = 2$ recognised as only value (accept as evidence only $t = 2$ used below). For the last 2 marks, no credit lost for reference to $t = \frac{2}{3}$. May be implied FT from **their** position. Accept one position followed through correctly.	5
(v)	$t = 0, 1$ give (0, 2) and (6, 3)	B1 B1 B1	At least one value $0 \le t < 2$ correctly calc. This need not be plotted Must be *x*-*y* curve. Accept sketch. Ignore curve outside interval for *t*. Accept unlabelled axes. Condone use of line segments. At least three correct points **used** in *x*-*y* graph or sketch. General shape correct. Do not condone use of line segments.	3
		19		