1. Fig. 1 shows four forces acting at a point. The forces are in equilibrium.

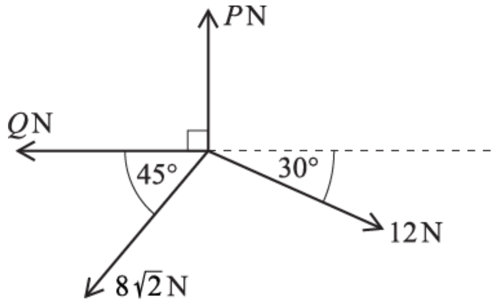


Fig. 1

Show that $P = 14$.

Find Q, giving your answer correct to 3 significant figures.

[5]

2. Fig. 7 illustrates a situation on a building site. An unexploded bomb is being lifted by light ropes that pass over smooth pulleys. The ropes are attached to winches V and W.

- The weight of the bomb is 7500 N.
- The winches are on horizontal ground and are at the same level.
- The sloping parts of the ropes from V and W are at angles α and β to the horizontal.
- The point P is level with the horizontal sections of the ropes and is 16 m and 9 m from the two pulleys, as shown.
- The winches are controlled so that the bomb moves in a vertical line through P. The tension in the rope attached to winch W is kept constant at 8000 N. The tension, T N, in the rope attached to winch V is varied.
- The distance between the top of the bomb, B, and the point P is d metres.

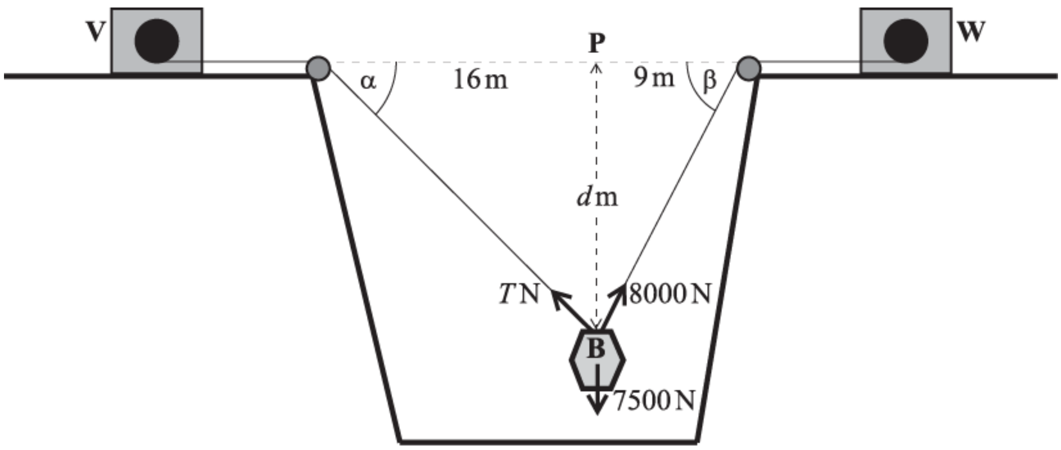


Fig. 7

At a particular stage in the lift, d = 12 and T = 6000.

(i) Find the values of $\cos\alpha$ and $\cos\beta$ at this stage.

[1]

(ii) Verify that, at this stage, the horizontal component of the bomb's acceleration is zero. Find the vertical component of its acceleration.

[7]

At a later stage, the bomb is higher up and so the values of d, T, α and β have all changed.

(iii) Show that $T = \dfrac{8000\cos\beta}{\cos\alpha}$.

Hence show that $T = \dfrac{4500\sqrt{d^2+256}}{\sqrt{d^2+81}}$.

[4]

(iv) Find the acceleration of the bomb when d = 6.75.

 [4]

(v) Explain briefly why it is not possible for the bomb to be in equilibrium with B at P.

What could you say about the acceleration of the bomb if B were at P and the tensions in the two ropes were equal?

[2]

3. A globe hangs on the end of a light wire that makes an angle of θ with the vertical. It is held in place by a light horizontal string, as shown in Fig. 7.

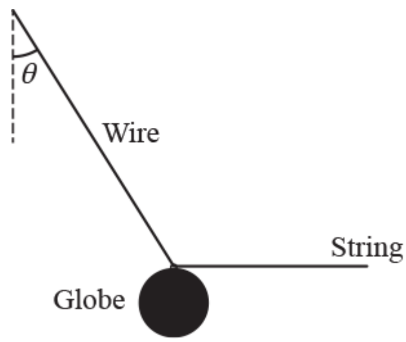


Fig. 7

Find the set of values of θ for which the tension in the string is less than the weight of the globe. **[4]**

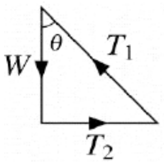
END OF QUESTION PAPER

Question			Answer/Indicative content	Marks	Guidance
1			$P = 8\sqrt{2}\sin 45° + 12\sin 30°$	M1	Considering equilibrium in the vertical direction
				M1	Resolution of forces of 12 N and $8\sqrt{2}$ N in the vertical direction. Do not allow sin-cos interchange for the 30° angle.
			P = 14	A1	Dependent on both M marks
			$Q + 8\sqrt{2}\cos 45° = 12\cos 30°$	B1	
			Q = 2.39	B1	**Examiner's Comments** This question was answered correctly by almost all candidates. A small number made sign errors, particularly when finding Q. There were also those who did not give Q to 3 significant figures, as requested in the question.
			Total	5	
2		i	cosα = 0.8, cosβ = 0.6.	B1	Or equivalent statements **Examiner's Comments** This was the second of the long questions on the paper, worth 18 marks. It was set in the context of raising an unexploded bomb from a hole on a building site. This question was quite challenging and many candidates were unsuccessful on the later parts. The question started with a straightforward piece of trigonometry for 1 mark, and almost all candidates were successful. Answers 0.8 and 0.6.
		ii	Horizontal forces → 8000cosβ - 6000cosα	M1	Do not allow sin-cos interchange
		ii	4800 – 4800 = 0 So the horizontal component of acceleration is 0	A1	Must state acceleration is zero

Question			Answer/Indicative content	Marks	Guidance
		ii	Vertical forces ↑ $T\sin\alpha + 8000 \sin\beta - 7500$	M1	Do not allow if the weight is missing Allow $T\cos\beta + 8000\cos\alpha - 7500$
		ii	$\sin\alpha$ (= $\cos\beta$) =0.6 and $\sin\beta$ (= $\cos\alpha$) = 0.8	B1	o.e. CAO May be seen or implied in the working
		ii	6400 + 3600 – 7500 = 2500	A1	CAO
		ii	Mass of bomb $\frac{7500}{9.8}$ (=765.3) kg	M1	
		ii	$\alpha = \frac{2500}{765.3} = 3.27$ The acceleration is 3.27 ms^{-1} upwards	A1	CAO Allow 3.26 **Examiner's Comments** The question then went on to consider the horizontal and vertical components of acceleration in a particular situation. The first demand was to show that the horizontal component is zero. Most candidates got this right but some lost a mark by failing to take the step of going from zero resultant force to zero acceleration; this was a given result and so a high standard of argument was expected. The question then went on to find the vertical component of acceleration and this elicited many good answers. A few candidates failed to convert the weight of the bomb to its mass, and some missed it out completely. There were fewer sin-cos interchanges than might have been the case a few years ago. Answer 3.27 ms^{-2}.
		iii	No horizontal acceleration ☐ Resultant = 0		
		iii	Horizontal forces → $8000\cos\beta - T\cos\alpha = 0$	M1	Horizontal must be indicated
		iii	$T = \frac{8000\cos\beta}{\cos\alpha}$	A1	
		iii	$\cos\alpha = \frac{16}{\sqrt{d^2+16^2}}, \quad \cos\beta = \frac{9}{\sqrt{d^2+9^2}}$	M1	

Question			Answer/Indicative content	Marks	Guidance
		iii	$T = 8000 \times \dfrac{\dfrac{9}{\sqrt{d^2+81}}}{\dfrac{16}{\sqrt{d^2+256}}} = \dfrac{4500\sqrt{d^2+256}}{\sqrt{d^2+81}}$	A1	**Examiner's Comments** The question then went on to consider a general situation during the lift. The first request was derive a given result for *T*. Many candidates lost marks here by not relating it to the horizontal direction. Some candidates may not have been aware that because this was a given result a high standard of argument was expected. Candidates were then asked to show that the given result for *T* could be written in a different form. While there were plenty of correct answers, there were also many that appeared to conjure the given result out of incorrect working.
		iv	When d = 6.75, $T = 4500 \times \dfrac{\sqrt{6.75^2+256}}{\sqrt{6.75^2+81}}$ (= 6946.2 ...)	B1	May be implied by subsequent working Note In this situation α = 22.9°, β = 36.9°
		iv	Vertical forces ↑ 6946.2sinα + 8000sinβ – 7500	M1	Their α and β. No sin-cos interchange. Note The forces are 2700 N and 4800N
		iv	= 0	A1	Condone any resultant force that rounds to 0 to the nearest integer.
		iv	So the (vertical) acceleration is zero.	A1	CAO **Examiner's Comments** In this part of the question, the bomb was at the height at which its vertical acceleration was zero and candidates were expected to use the result given at the end of part (iii) to discover this. Only the stronger candidates were successful. Many of those who attempted to find the equation of motion used the wrong angles or the wrong tensions, or forgot about the weight completely. Answer Acceleration = 0 ms^{-2}
		iv	**Alternative** Vertical forces ↑ T sinα + 8000sinβ – 7500		
		iv	$4500 \times \dfrac{\sqrt{6.75^2+256}}{\sqrt{6.75^2+81}} \times \dfrac{6.75}{\sqrt{6.75^2+256}} + 8000 \times \dfrac{6.75}{\sqrt{6.75^2+81}} - 7500$	M1	

Question			Answer/Indicative content	Marks	Guidance
		iv		B1	
		iv	$12500 \times \frac{6.75}{11.25} - 7500 = 0$	A1	
		iv	So the (vertical) acceleration is zero.	A1	CAO
		v	When at P there would be no vertical components of the tensions to counteract the weight.	B1	
		v	The acceleration would be *g* vertically downwards.	B1	The acceleration must be stated to be *g* **Examiner's Comments** In part (ii) the bomb was in a position where it was accelerating upwards. In part (iv) it was in a position where equilibrium was possible but there could be no upwards acceleration. The final part of the question considered the hypothetical situation where the bomb was at the top and so was at the same level as the winches. Candidates were asked to explain why equilibrium was impossible in this situation and to state the acceleration. While there were some excellent explanations many were garbled or wrong. Many candidates said there would be zero acceleration. Answer g ms^{-2} vertically downwards.
			Total	18	

Question			Answer/Indicative content	Marks	Guidance
3			T_1 and T_2 are tensions in wire and string respectively; the globe has mass m		
			Resolve vertically: $T_1 \cos\theta = mg$ $T_1 = \frac{mg}{\cos\theta}$	M1(AO 3.1b)	Allow sin/cos interchange for 1st M1 only
			Resolve horizontally: $T_2 = T_1 \sin\theta$	M1(AO 3.3)	Use of trig identity
			$T_2 = \frac{mg}{\cos\theta} \times \sin\theta = mg\tan\theta$	M1(AO 2.1)	
			$mg\tan\theta < mg$ for $\tan\theta < 1$		
			$\theta < 45°$	A1(AO 2.2a)	Inequality clearly stated
			Alternative method		
			 Triangle of forces	M1	Forces shown, correct arrow directions
			Maximum T_2 is when $T_2 = W$	M1	Equating T_2 and weight for limiting case
			In this case $\theta = \arctan(1)$	M1	Use of trigonometry or isosceles triangle
			Hence $\theta < 45°$	A1	Inequality clearly stated
				[4]	
			Total	4	