3.2 Mechanics: Forces and Newton's Laws: 2-hour Pack

Total Marks

EDEXCEL 9MA0 · Calculator allowed · about 120 minutes

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 Two blocks A (mass 4 kg) and B (mass 2 kg) are connected by a light inextensible string and lie on smooth horizontal ground. A horizontal force of 18 N pulls block A, with B connected behind it, so both move with the same acceleration. Find the acceleration of the system.

(Total for Question 1 is 2 marks)

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2 Two blocks connected by a light inextensible string move with acceleration 3 m/s^2. Block B, of mass 2 kg, has no horizontal force acting on it other than the tension in the string. Find the tension in the string.

(Total for Question 2 is 2 marks)

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3 A block of mass 10 kg rests in equilibrium on a smooth plane inclined at 25 degrees to the horizontal, held by a light inextensible string parallel to the line of greatest slope. Take g = 9.8 m/s^2. Find the tension in the string, giving your answer to 3 significant figures.

(Total for Question 3 is 2 marks)

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4 A block of mass 6 kg rests in equilibrium on a smooth plane inclined at 40 degrees to the horizontal, held by a light inextensible string parallel to the line of greatest slope. Take g = 9.8 m/s^2. Find the normal reaction between the block and the plane, giving your answer to 3 significant figures.

(Total for Question 4 is 2 marks)

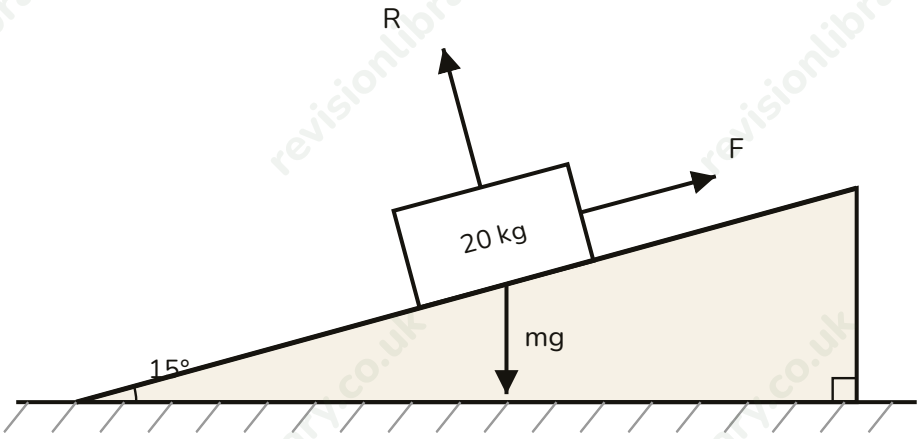
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5 A crate of mass 8 kg is pulled along smooth horizontal ground by a force of magnitude 25 N acting at 40 degrees above the horizontal. Find the acceleration of the crate, giving your answer to 3 significant figures.

(Total for Question 5 is 3 marks)

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6 A crate of mass 20 kg rests on a rough plane inclined at 15 degrees to the horizontal. The coefficient of friction between the crate and the plane is 0.35. The crate is modelled as a particle. Take $g = 9.8\ m/s^2$.



(a) Show that the crate remains in equilibrium on the plane. **(3)**

(b) Find the magnitude of the friction force acting on the crate while it is at rest. **(2)**

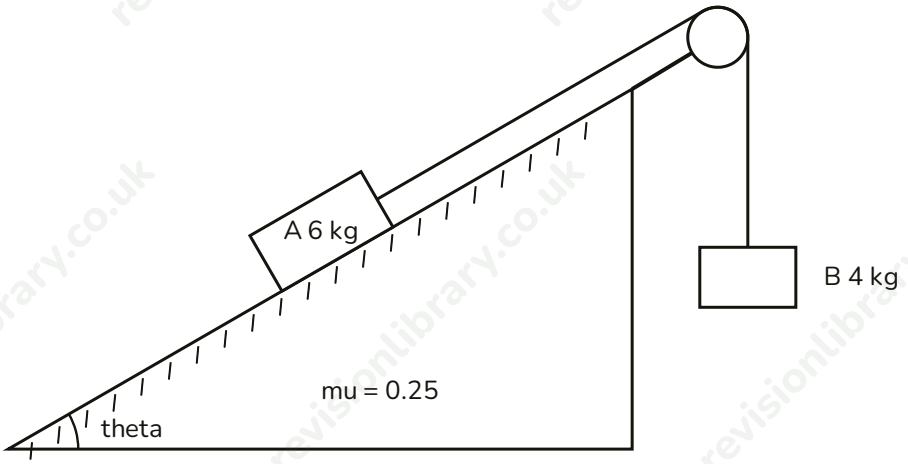
(c) A force P is now applied to the crate, parallel to and directed up the line of greatest slope. Find the minimum value of P required to move the crate up the plane. **(4)**

(d) State one assumption made about the crate in this model. **(1)**

(Total for Question 6 is 10 marks)

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7 Particle A, of mass 6 kg, lies on a rough plane inclined at angle θ to the horizontal. A is connected by a light inextensible string, passing over a smooth light pulley fixed at the top of the plane, to particle B, of mass 4 kg, which hangs freely below the pulley. The coefficient of friction between A and the plane is 0.25. The system is released from rest. Take $g = 9.8$ m/s^2.



(a) Given that θ = 30 degrees, show that the system remains in equilibrium. **(4)**

(b) The plane is instead inclined at 60 degrees (all else unchanged). Show that the system does not remain in equilibrium, and find the resulting acceleration of the system. **(6)**

(Total for Question 7 is 10 marks)

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8 A particle P of mass 2 kg moves on a smooth horizontal plane under the action of two constant forces, F1 = (3i + 5j) N and F2 = (-i + 2j) N, where i and j are perpendicular unit vectors in the plane. The weight of P and the normal reaction from the plane are not considered further, as they act perpendicular to the plane of motion.

(a) Find the resultant force acting on P, giving your answer in the form (π + qj) N. **(2)**

(b) Find the acceleration of P, in the form (π + qj) m/s^2. **(2)**

(c) Find the magnitude of the acceleration, giving your answer to 3 significant figures. **(2)**

(d) Given that P starts at rest, find the speed of P after 4 seconds, giving your answer to 3 significant figures. **(3)**

(e) Find, to the nearest degree, the angle the direction of motion after 4 seconds makes with the vector i. **(2)**

(Total for Question 8 is 11 marks)

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9 A particle of mass 4 kg is pulled along rough horizontal ground by a horizontal force of 30 N. The resistance to motion is modelled as a constant frictional force of magnitude 0.25 times the normal reaction between the particle and the ground. Take $g = 9.8$ m/s^2. Find the acceleration of the particle.

(Total for Question 9 is 3 marks)

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10 Particles A and B, of mass 6 kg and 2 kg respectively, are connected by a light inextensible string which passes over a smooth fixed pulley. The particles hang at rest on either side of the pulley and are released from rest. Take $g = 9.8$ m/s^2. Find the acceleration of the system and the tension in the string.

(Total for Question 10 is 4 marks)

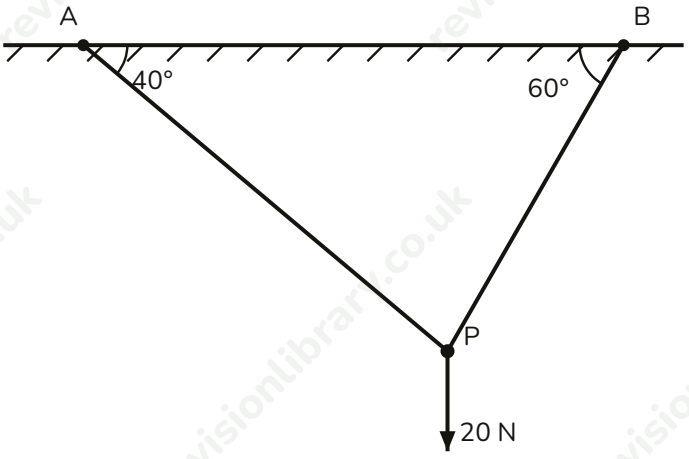
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11 A box of mass 6 kg is pulled along rough horizontal ground by a force of magnitude 40 N acting at 25 degrees above the horizontal. The coefficient of friction between the box and the ground is 0.3. Take $g = 9.8$ m/s^2. Find the acceleration of the box, giving your answer to 3 significant figures.

(Total for Question 11 is 4 marks)

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12 A particle P, of weight 20 N, hangs in equilibrium, held by two light inextensible strings attached to a fixed horizontal ceiling, as shown in the diagram. String PA makes an angle of 40 degrees with the horizontal ceiling and string PB makes an angle of 60 degrees with the horizontal ceiling, on the opposite side of P.



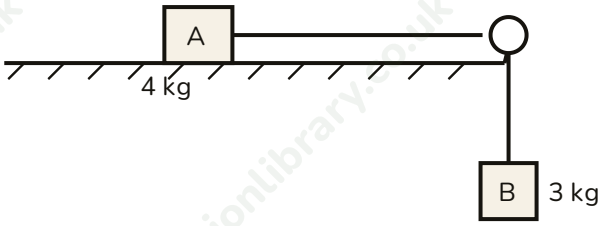
(a) Find the tension in string PA, giving your answer to 3 significant figures. **(2)**

(b) Find the tension in string PB, giving your answer to 3 significant figures. **(2)**

(Total for Question 12 is 4 marks)

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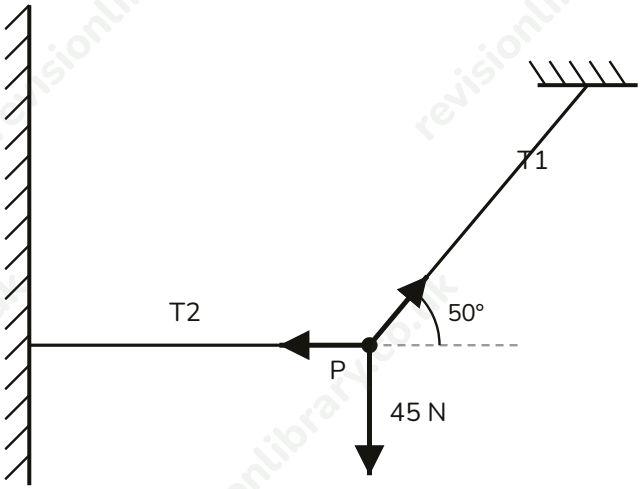
13 Particle A, of mass 4 kg, lies on a rough horizontal table. The coefficient of friction between A and the table is 0.2. A light inextensible string attached to A passes over a smooth pulley fixed at the edge of the table and hangs vertically, carrying particle B, of mass 3 kg, freely at its other end, as shown in the diagram. The system is released from rest. Take $g = 9.8$ m/s^2. Find the acceleration of the system and the tension in the string.



(Total for Question 13 is 3 marks)

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14 A particle P of weight 45 N is held in equilibrium by two light inextensible strings. One string is inclined at 50 degrees to the horizontal and is attached to a fixed point above and to one side of P; the other string is horizontal, attached to a fixed point on a wall.



(a) Find the tension T1 in the inclined string. **(3)**

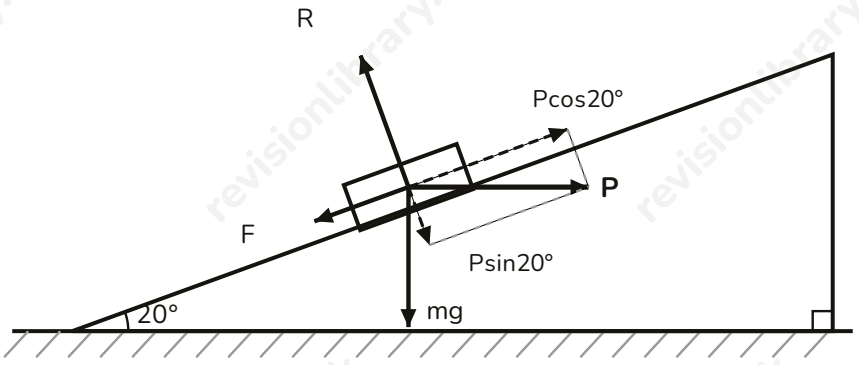
(b) Find the tension T2 in the horizontal string. **(3)**

(c) The horizontal string is cut. Find the angle the remaining string now makes with the horizontal, and the new tension in it, for P to hang in equilibrium. **(3)**

(Total for Question 14 is 9 marks)

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15 A block of mass 10 kg rests on a rough plane inclined at 20 degrees to the horizontal. The coefficient of friction between the block and the plane is 0.4. A horizontal force of magnitude P newtons is applied to the block, directed into the slope, so that it has a component acting up the line of greatest slope. Take $g = 9.8\ m/s^2$.



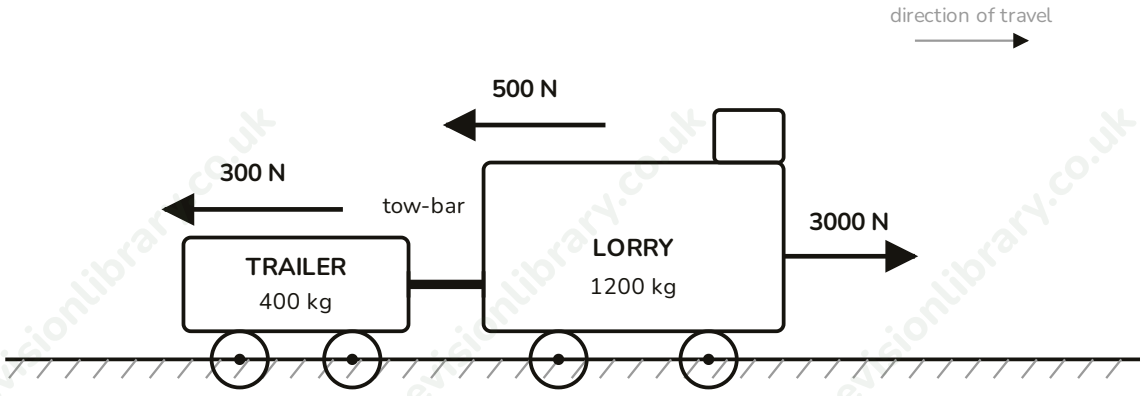
(a) Given that P = 0, show that the block remains in equilibrium. **(3)**

(b) Find, to 3 significant figures, the minimum value of P required to move the block up the plane. **(6)**

(Total for Question 15 is 9 marks)

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16 A lorry of mass 1200 kg tows a trailer of mass 400 kg along a straight horizontal road, connected by a light rigid horizontal tow-bar. The lorry's engine produces a driving force of 3000 N. The resistances to motion are 500 N on the lorry and 300 N on the trailer. Both vehicles are modelled as particles, and the tow-bar as a light rod. Take $g = 9.8$ m/s^2 (not required numerically in this question).



(a) Find the acceleration of the lorry and trailer. **(3)**

(b) Find the force in the tow-bar, stating whether it is a tension or a thrust. **(3)**

(c) The engine is switched off while both vehicles are moving, so the driving force becomes zero; the resistances are unchanged. Find the new deceleration of the system and the new force in the tow-bar, stating whether it is a tension or a thrust. **(4)**

(d) State an assumption made about the tow-bar in this model, and explain why it allows the lorry and trailer to have the same acceleration. **(2)**

(Total for Question 16 is 12 marks)

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17 A particle P of mass 4 kg moves on a smooth horizontal plane under the action of two constant forces, F1 = (5i - 2j) N and F2 = (1i + 6j) N, where i and j are perpendicular unit vectors in the plane. Given that P starts at rest, find the speed of P after 3 seconds, giving your answer to 3 significant figures.

(Total for Question 17 is 4 marks)

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18 A car of mass 1200 kg tows a trailer of mass 400 kg along a straight horizontal road using a light rigid tow-bar. The car's engine provides a driving force of 2800 N. The resistance to the motion of the car is 300 N and the resistance to the motion of the trailer is 100 N.

(a) Find the acceleration of the car and trailer. **(3)**

(b) Find the tension in the tow-bar. **(2)**

(Total for Question 18 is 5 marks)

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Mark scheme · 3.2 Mechanics: Forces and Newton's Laws: 2-hour Pack

Question 1

whole-system equation: 18 = (4+2)a **M1**

3 m/s^2 cao **A1**

Answer: 3 m/s^2

Question 2

equation of motion for B: T = ma with m=2, a=3 **M1**

6 N cao **A1**

Answer: 6 N

Question 3

resolve parallel to the plane: T = mg sin25 **M1**

awrt 41.4 N **A1**

Answer: 41.4 N (3 s.f.)

Question 4

resolve perpendicular to the plane: R = mg cos40 **M1**

awrt 45.0 N **A1**

Answer: 45.0 N (3 s.f.)

Question 5

horizontal component of the force = 25cos40 (oe) **M1**

use F=ma with the horizontal component: a = 25cos40/8 **M1**

awrt 2.39 m/s^2 **A1**

Answer: 2.39 m/s^2 (3 s.f.)

Question 6

(a) compute component of weight down the plane: mg sin15 = 50.7 N (awrt) **M1**

(a) compute maximum available friction: μ mg cos15 = 66.3 N (awrt) **M1**

(a) cso: since 50.7 < 66.3, the required friction is within the limiting value, so the crate remains in equilibrium **A1**

(a) Answer: Remains in equilibrium (50.7 N < 66.3 N)

(b) recognising friction is not limiting, so F = mg sin15 (not μ R) **B1**

(b) F = 50.7 N (awrt), acting up the plane **B1**

(b) Answer: F = 50.7 N up the plane

(c) at limiting equilibrium (about to move up), friction acts down the plane at its maximum: F = μ mg cos15 **M1**

(c) equation: P = mg sin15 + μ mg cos15 (oe) **A1**

(c) substitute values: P = 50.73 + 66.26 **M1**

(c) P = 117 N (awrt) **A1**

(c) Answer: P = 117 N

(d) the crate is modelled as a particle (a single point with no size/shape), so rotational effects are ignored **B1**

(d) Answer: The crate is modelled as a particle.

Question 7

(a) resolves perpendicular to the plane: R = mA g cos30 = 50.9 N (awrt) **M1**

(a) uses F = μ R for the maximum friction: Fmax = 0.25 x 50.9 = 12.7 N (awrt) **M1**

(a) compare tension required to hold B (T = mBg = 39.2 N) with weight component of A along plane (mA g sin30 = 29.4 N); required friction = |39.2 - 29.4| = 9.8 N **M1**

(a) cso: since 9.8 N < 12.7 N (Fmax), the required friction is available, so the system remains in equilibrium **A1**

(a) Answer: Remains in equilibrium (required friction 9.8 N < max friction 12.7 N)

(b) find new R = mA g cos60 = 29.4 N and Fmax = μ R = 7.35 N **M1**

(b) compare mA g sin60 (50.9 N, awrt) with mBg (39.2 N): difference = 11.7 N (awrt) **M1**

(b) cso: since 11.7 N > 7.35 N, friction cannot hold the system, so A slides down the plane and B rises; not in equilibrium **A1**

(b) equation of motion for whole system: mA g sin60 - mBg - Fmax = (mA+mB)a **M1**

(b) correct substitution: 50.92 - 39.2 - 7.35 = 10a **A1**

(b) a = 0.44 m/s^2 (awrt) **A1**

(b) Answer: Not in equilibrium; a = 0.44 m/s^2 (A slides down, B rises)

Question 8

(a) add components: (3-1)i + (5+2)j **M1**

(a) resultant = (2i + 7j) N cao **A1**

(a) Answer: (2i + 7j) N

(b) a = F/m = (2i+7j)/2 **M1**

(b) a = (1i + 3.5j) m/s^2 cao **A1**

(b) Answer: (i + 3.5j) m/s^2

(c) $|a| = \sqrt{1^2 + 3.5^2}$ **M1**

(c) |a| = 3.64 m/s^2 (awrt) **A1**

(c) Answer: 3.64 m/s^2

(d) v = u + at with u = 0, t = 4, using the vector acceleration **M1**

(d) v = (4i + 14j) m/s **A1**

(d) speed = |v| = 14.6 m/s (awrt) **A1**

(d) Answer: 14.6 m/s

(e) tan(angle) = 14/4 (oe, using components of v) **M1**

(e) angle = 74 degrees (awrt, nearest degree) **A1**

(e) Answer: 74 degrees

Question 9

R = mg = 4(9.8) = 39.2, friction = 0.25(39.2) = 9.8 **M1**

resultant force = 30 - 9.8, then a = resultant/4 **M1**

5.05 m/s^2 cao **A1**

Answer: 5.05 m/s^2

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Question 10

equations of motion 6g - T = 6a and T - 2g = 2a, combined to give 4g = 8a **M1**

a = 4.9 m/s^2 cao **A1**

substitute into T = 6(g-a) or T = 2(g+a) **M1**

T = 29.4 N cao **A1**

Answer: a = 4.9 m/s^2, T = 29.4 N

Question 11

resolve vertically: R + 40sin25 = mg, so R = mg - 40sin25 (oe) **M1**

friction = μ R **M1**

resolve horizontally: 40cos25 - friction = ma **M1**

awrt 3.95 m/s^2 **A1**

Answer: 3.95 m/s^2 (3 s.f.)

Question 12

(a) resolve horizontally and vertically to form simultaneous equations: $T_A \cos 40 = T_B \cos 60$ and $T_A \sin 40 + T_B \sin 60 = 20$ (oe) **M1**

(a) awrt 10.2 N **A1**

(a) Answer: 10.2 N (3 s.f.)

(b) substitute back into the simultaneous equations (ft from part (a)) **M1**

(b) awrt 15.6 N **A1**

(b) Answer: 15.6 N (3 s.f.)

Question 13

equations of motion for A and B, e.g. T - μ(4)(9.8) = 4a and 3(9.8) - T = 3a, combined to eliminate T and find a **M1**

a = 3.08 m/s^2 cao **A1**

T = 20.16 N cao (ft from a) **B1**

Answer: a = 3.08 m/s^2, T = 20.16 N

Question 14

(a) resolving vertically: T1 sin50 = 45 **M1**

(a) T1 = 45/sin50 (oe) **A1**

(a) T1 = 58.7 N (awrt) **A1**

(a) Answer: T1 = 58.7 N

(b) resolving horizontally: T2 = T1 cos50 (oe, or T2 = 45/tan50) **M1**

(b) T2 = 58.74 cos50 (oe) **A1**

(b) T2 = 37.8 N (awrt) **A1**

(b) Answer: T2 = 37.8 N

(c) with only one string and the weight acting, the string must be vertical (90 degrees to horizontal) for horizontal equilibrium **B1**

(c) resolving vertically: T = 45 (weight only supported by the string) **M1**

(c) angle = 90 degrees, T = 45 N **A1**

(c) Answer: The string becomes vertical (90 degrees); T = 45 N

Question 15

(a) compare tan(θ) with μ, or equivalently compute mg sin20 and μ mg cos20 **M1**

(a) tan20 = 0.364 (awrt), or mg sin20 = 33.5 N and μ mg cos20 = 36.8 N (awrt) **A1**

(a) cso: since tan20 (0.364) < μ (0.4) [equivalently 33.5 N < 36.8 N], the block remains in equilibrium **A1**

(a) Answer: Remains in equilibrium (tan20 = 0.364 < 0.4)

(b) resolving perpendicular to the plane: R = mg cos20 + P sin20 **M1**

(b) correct expression for R in terms of P **A1**

(b) resolving along the plane at limiting equilibrium (motion up impending, friction acting down the plane): P cos20 = mg sin20 + μ R **M1**

(b) correct equation with R substituted: P cos20 = mg sin20 + μ(mg cos20 + P sin20) **A1**

(b) rearrange to make P the subject: P(cos20 - μ sin20) = mg(sin20 + μ cos20) **M1**

(b) P = 87.6 N (awrt) **A1**

(b) Answer: P = 87.6 N

Question 16

(a) whole system equation: 3000 - 500 - 300 = (1200+400)a **M1**

(a) 2200 = 1600a (oe) **A1**

(a) a = 1.375 m/s^2 cao **A1**

(a) Answer: a = 1.375 m/s^2

(b) equation of motion for trailer alone: T - 300 = 400a **M1**

(b) T = 300 + 400(1.375) **A1**

(b) T = 850 N cao, a tension (bar pulls trailer forward) **A1**

(b) Answer: T = 850 N (tension)

(c) whole system equation with zero driving force: -800 = 1600a **M1**

(c) deceleration = 0.5 m/s^2 **A1**

(c) equation of motion for trailer: T - 300 = 400(-0.5) **M1**

(c) T = 100 N cao, still a tension **A1**

(c) Answer: Deceleration = 0.5 m/s^2; T = 100 N (tension)

(d) the tow-bar is modelled as light and rigid (inextensible) **B1**

(d) because it is rigid and inextensible, the distance between the lorry and trailer cannot change, so their velocities and accelerations must be equal at all times **B1**

(d) Answer: The tow-bar is light and rigid; this fixes the separation of the two vehicles so they share the same acceleration.

Question 17

resultant force = (6i + 4j) N **M1**

a = resultant/mass = (1.5i + j) m/s^2 **M1**

v = u + at with u=0: v = (4.5i + 3j) m/s **M1**

awrt 5.41 m/s **A1**

Answer: 5.41 m/s (3 s.f.)

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Question 18

(a) resultant force on the whole system = driving force - (resistance on car + resistance on trailer) (oe) **M1**

(a) = (mass of car + mass of trailer) x a (oe) **M1**

(a) 1.5 m/s^2 cao **A1**

(a) Answer: 1.5 m/s^2

(b) consider the trailer alone: T - 100 = 400(1.5) (oe), using a from part (a), ft **M1**

(b) 700 N cao **A1**

(b) Answer: 700 N

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