TENSION & PULLEY SYSTEMS

Tension

1. A rope is attached to a block and exerts a tension force on the block. Which of the following is true about the direction of the tension force ? (Select all that apply)
   - A It may act away from the block or towards the block depending on the situation
   - B It acts parallel to the rope
   - C It acts away from the block
   - D It acts perpendicular to the rope

2. Assuming a rope is massless, the tension forces at both ends of an uninterrupted length of rope are…
   - A always equal
   - B sometimes equal, depend on the other forces acting on the rope
   - C sometimes equal, depending on the acceleration of the rope
   - D never equal

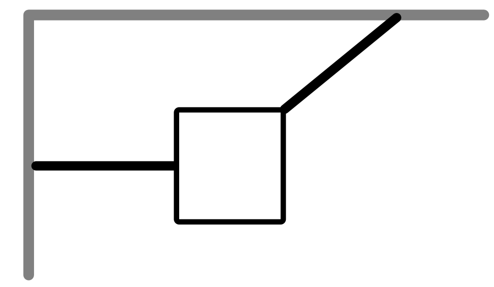
3. A person pulls on a rope attached to a box so it slides across the floor. The magnitude of the force exerted on the rope by the box is equal to… (Select all that apply)
   - A the magnitude of the force exerted on the box by the rope
   - B the magnitude of the force exerted on the rope by the person
   - C the magnitude of the force exerted on the person by the rope
   - D the magnitude of the tension force in the rope

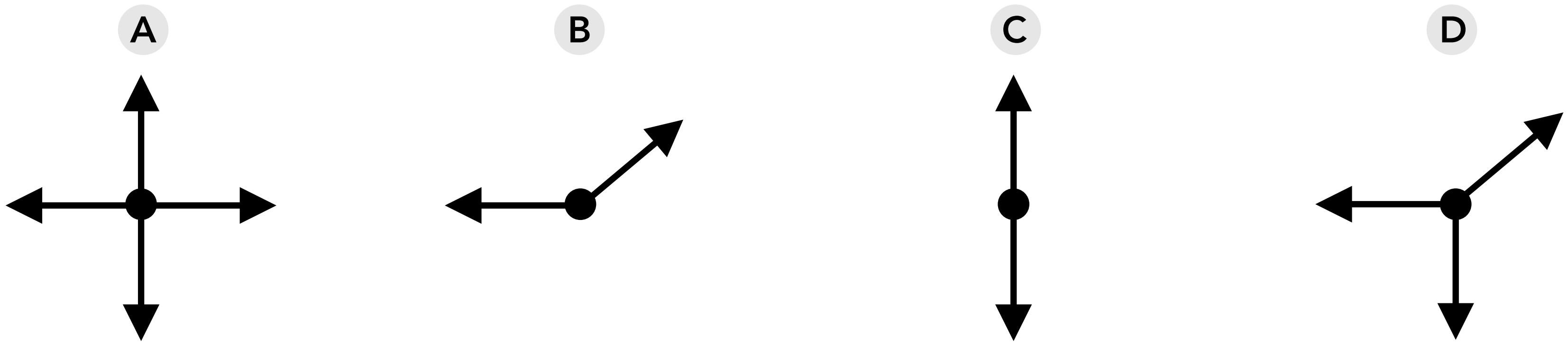
4. A 15 kg block is hanging from the ceiling by a rope. What is the tension in the rope?
   - A 15 N
   - B 30 N
   - C 147 N
   - D Cannot be determined

5. A rope is attached to the top of a block of mass m which is resting on a table. The rope is then pulled upwards with a force of F so that the block remains in contact with the table. Which of the following represents the normal force between the block and the table?
   - A F
   - B $mg - F$
   - C $F + mg$
   - D mg

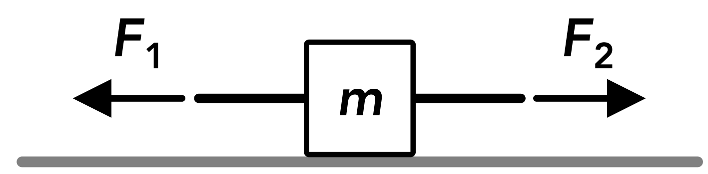
6. A box is sitting on the floor with two ropes attached to it, one on the left and one on the right. One person grabs the left rope and pulls the box to the left and another person grabs the right rope and pulls the box to the right at the same time. If the box accelerates to the right, which of the following is true?
   - A The tension in the right rope must be greater than the tension in the left rope
   - B The tension in the left rope must be greater than the tension in the right rope
   - C The tension in the right rope must be greater than the tension in the left rope, and there must be no friction
   - D The tension in the left rope must be greater than the tension in the right rope, and there must be no friction

7. A 10 kg block is suspended by two ropes as shown on the right. Which of the following would be a free body diagram of the block?



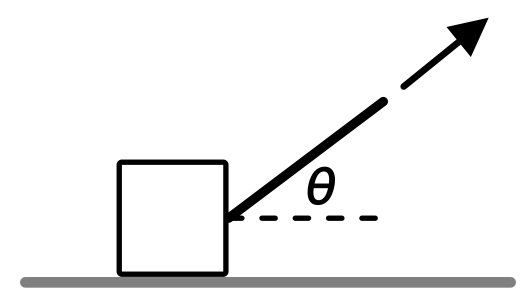


8. Two forces are applied to two ropes attached to a block which is on a frictionless surface. If the block accelerates to the right, which of the following represents the magnitude of the acceleration?



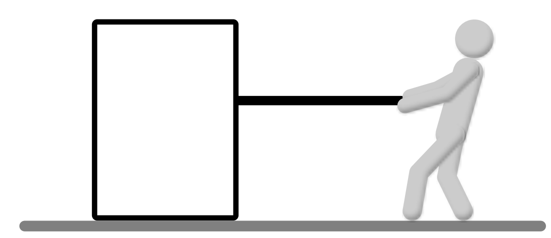
- A $\dfrac{F_2}{m}$
- B $(F_2 - F_1)m$
- C $\dfrac{F_2 - F_1}{m}$
- D $F_2 m$

9. A block is pulled by the tension force T in a rope which is at an angle above the horizontal as shown on the right. What is the magnitude of the component of the tension force which is parallel to the ground?



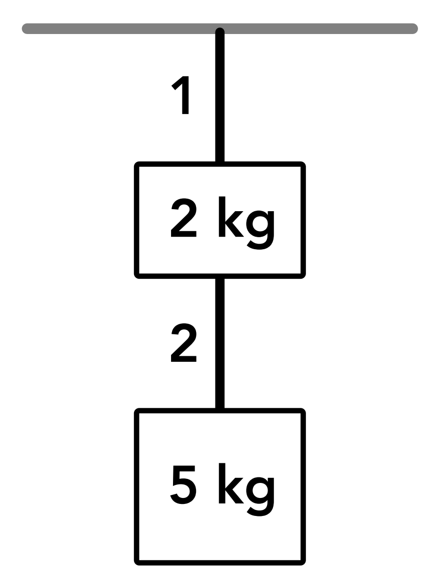
- A T
- B $T\cos(\theta)$
- C $T\sin(\theta)$
- D $T/2$

10. A person pulls on a rope attached to a box as shown on the right. Due to friction, the box does not move. Which of the following is true? (Select all that apply)



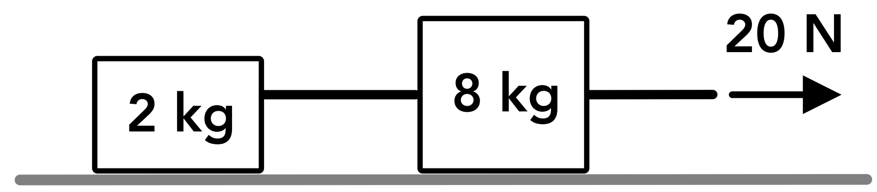
- A The friction force exerted on the box by the floor is equal in magnitude to the friction force exerted on the person by the floor
- B The tension in the rope is twice the magnitude of the force exerted on the rope by the person
- C The friction force exerted on the person by the floor is equal in magnitude to the tension in the rope
- D The tension in the rope is half the magnitude of the friction force exerted on the box by the floor

11. Two blocks are hung from the ceiling by 2 ropes as shown on the right, and then rope 1 is cut. What is the tension in rope 2 the moment after rope 1 is cut?

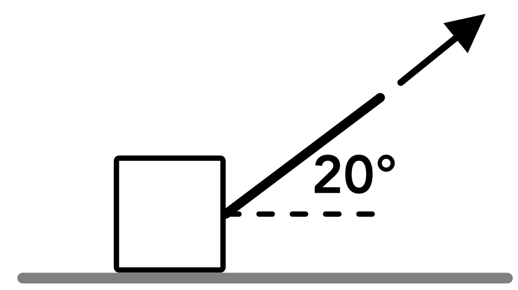


- A 68.6 N
- B 49 N
- C 19.6 N
- D 0 N

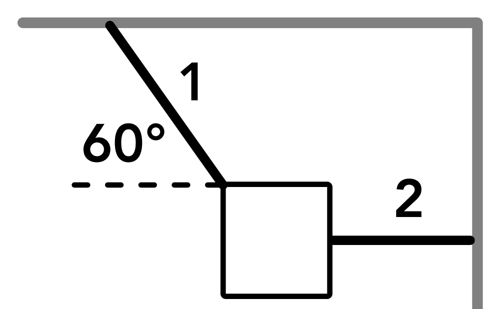
12. Two blocks on a frictionless surface are connected by a rope and pulled by a second rope as shown on the right. What is the tension in the rope between the two blocks?



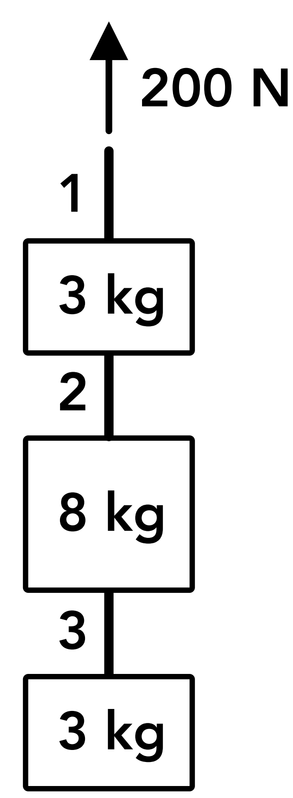
13. A 5 kg block is pulled by a 40 N tension force at an angle as shown on the right. If the coefficient of kinetic friction between the block and the floor is 0.4, what is the acceleration of the block?



14. A 20 kg block is suspended by two ropes as shown on the right. What is the tension in each rope?



15. Three blocks are hanging and connected by ropes as shown on the right. A 200 N force is applied to the top rope (rope 1). What is the tension in each of the three ropes?



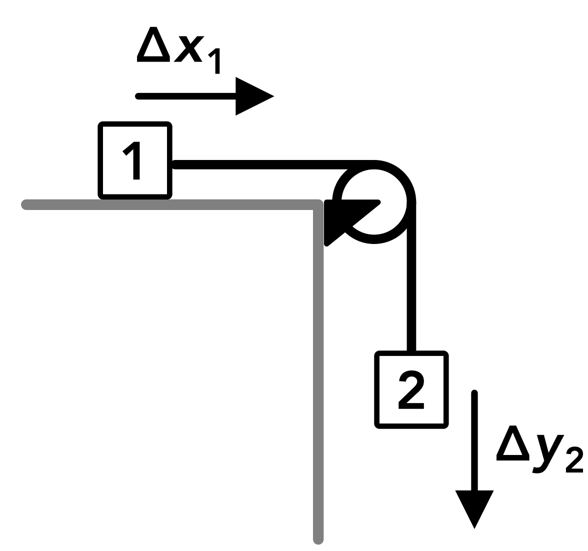
Pulley Systems

16. Which of the following is always true when a rope bends around a pulley?
    - A The magnitudes of the tension forces at both ends of the rope are equal
    - B The direction of the tension force changes (compared to a straight rope)
    - C The magnitudes of the tension forces at both ends of the rope are never equal
    - D The direction of the tension force stays the same (compared to a straight rope)

17. Which of the following is assumed about an ideal pulley? (Select all that apply)
    - A It is frictionless
    - B It rotates with a constant speed
    - C It has no mass or rotational inertia
    - D It only rotates in one direction

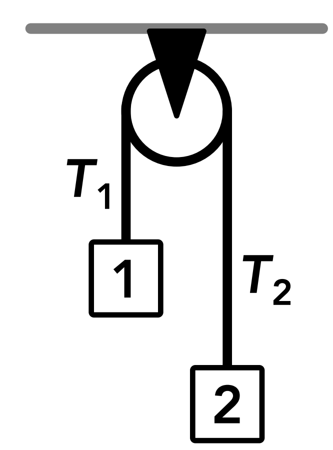
18. Which of the following is true for a rope that passes around an ideal pulley?
    - A The tension forces at each end of the rope are only equal if the rope moves at a constant speed
    - B The tension force is greater at one end of the rope
    - C The tension forcess at each end of the rope are always equal
    - D None of the above

19. Two blocks are connected by a rope which passes over a pulley on the corner of a table as shown on the right. Over a period of 2 seconds the displacement of block 1 is Δx_1 and the displacement of block 2 is Δy_2. How are the displacements related?



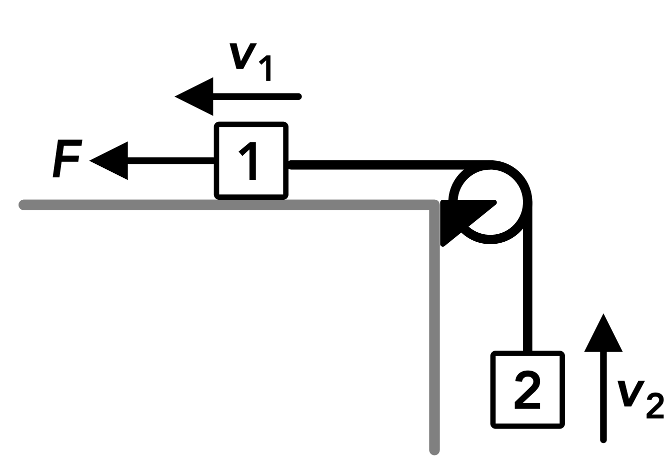
    - A $\Delta x_1 = \Delta y_2$
    - B $\Delta x_1 < \Delta y_2$
    - C $\Delta x_1 > \Delta y_2$
    - D Cannot be determined

20. Two blocks are connected by a rope which passes over a pulley as shown on the right. T_1 and T_2 are the tensions in the rope on each side of the pulley. If the pulley is not ideal and has rotational inertia, which of the following is true? (Select all that apply)



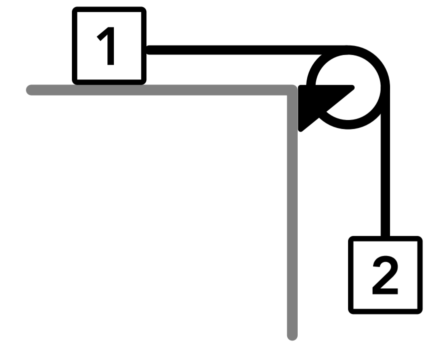
    - A We can assume T_1 is equal to T_2
    - B We cannot assume T_1 is equal to T_2
    - C T_1 and T_2 must be different
    - D T_2 must be greater than T_1

21. Two blocks are connected by a rope which passes over a pulley on the corner of a table as shown on the right, and a force is applied to block 1. How are the speeds of block 1 and 2 related at one moment in time?



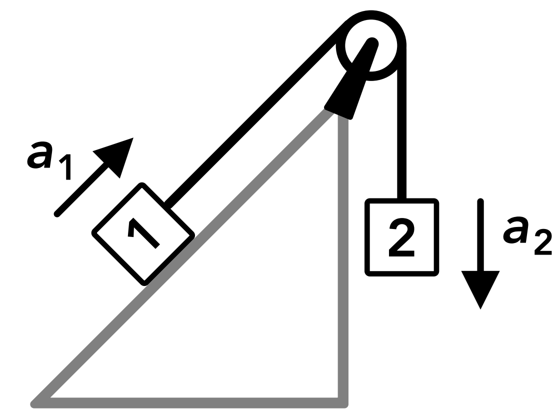
    - A $v_1 > v_2$
    - B $v_1 = v_2$
    - C $v_1 < v_2$
    - D Cannot be determined

22. Two blocks are connected by a rope which passes over an ideal pulley as shown on the right. Block 1 has a mass of 10 kg and block 2 has a mass of 9 kg. If there is no friction between block 1 and the table, which of the following is true?



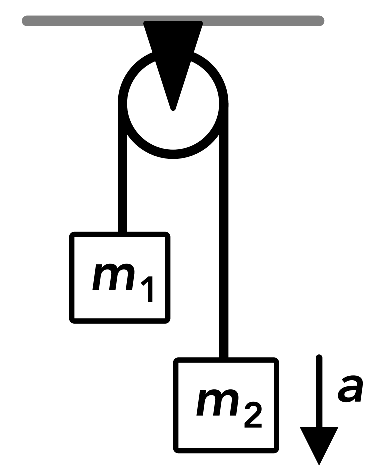
- A Block 1 and block 2 do not move
- B Block 1 and block 2 move with a constant velocity
- C Block 2 accelerates and block 1 does not move
- D Block 1 and block 2 accelerate

23. Two blocks are connected by a rope which passes over a pulley which has some mass and rotational inertia as shown on the right. Block 1 is on an an incline and a friction force acts on block 1 against its motion. Block 2 has a greater mass than block 1 and the two blocks accelerate. How are the accelerations of the blocks related?



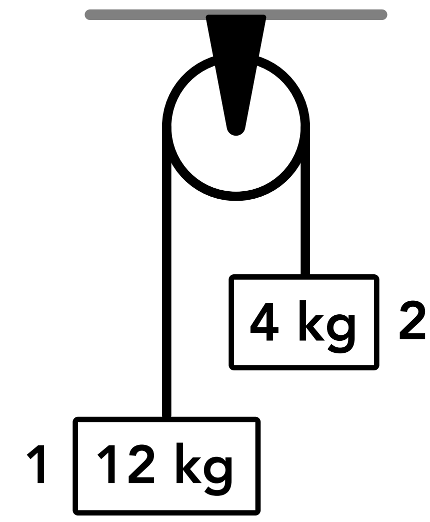
- A $a_1 < a_2$
- B $a_1 > a_2$
- C $a_1 = a_2$
- D Cannot be determined

24. Two blocks are connected by a rope which passes over an ideal pulley as shown on the right. m_2 is greater than m_1 and the blocks accelerate. Which of the following represents the magnitude of the acceleration?

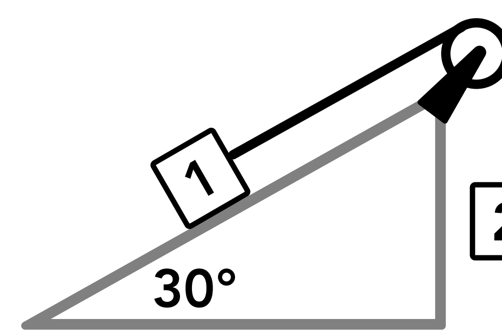


- A $\frac{m_2 g - m_1 g}{m_1 + m_2}$
- B $\frac{m_2 g}{m_1 + m_2}$
- C $\frac{m_1 g + m_2 g}{m_1 + m_2}$
- D g

25. Two blocks are connected by a rope which passes over an ideal pulley as shown on the right. What is the tension in the rope?



26. Two blocks are connected by a rope which passes over an ideal pulley as shown on the right. Block 1 is on an incline and the coefficient of kinetic friction between block 1 and the surface is 0.4. Block 1 has a mass of 5 kg and block 2 has a mass of 20 kg. What is the acceleration of block 2?



Answers

1. B, C
2. A
3. A, B, C, D
4. C
5. B
6. A
7. D
8. C
9. B
10. A, C
11. D
12. 4 N
13. 4.7 m/s²
14. T_1 = 226.3 N, T_2 = 113.2 N
15. T_1 = 200 N, T_2 = 157.2 N, T_3 = 42.9 N
16. B
17. A, C
18. C
19. A
20. B
21. B
22. D
23. C
24. A
25. 58.8 N
26. 6.2 m/s²

Answers - Tension

1. **Answer: B, C**
A tension force is always a pulling force which acts away from the object that it's exerted on, and a tension force is always parallel to the rope (or string, cable, wire, etc).

2. **Answer: A**
If a rope is massless, we always assume that the tension forces at both ends of the rope are equal for an uninterrupted length of rope (which means the rope does not contact anything else except the objects at the two ends). If the rope goes around an ideal pulley (which is massless and frictionless) then the tension force at both ends of the rope are still equal.

3. **Answer: A, B, C, D**
The tension force at both ends of the rope are equal in magnitude, and the forces exerted by two contacting objects on each other are equal in magnitude (Newton's 3rd law).

4. **Answer: C**
The net force on the block is zero (we assume the block is not accelerating). There is an upwards tension force acting on the block from the rope and a downwards weight force. If the net force is zero then the tension force is equal to the weight force, $F_g = mg$.

5. **Answer: B**
The upwards tension force on the block is equal to the applied force F, there is a downwards weight force on the block and an upwards normal force from the table. If the block remains in contact with the table then the block does not accelerate and the net force on the block is zero.
$\sum F_y = ma_y \qquad F + F_n - mg = m(0) \qquad F_n = mg - F$

6. **Answer: A**
The tension in the right rope is exerted on the box to the right, the tension in the left rope is exerted on the box to the left, and if there is a friction force between the box and the floor it acts to the left because the box is moving to the right. The box accelerates to the right so the right tension force must be greater than the left tension force alone (if there's no friction), or it must be greater than the sum of the left tension force and the friction force (in which case the right tension force is still greater than the left tension force).

7. **Answer: D**
The tension forces exerted on the block from each rope act parallel to that rope, and there is a downwards weight force on the block.

8. **Answer: C**
The forces applied to the ends of the ropes are equal in magnitude to the forces exerted on the block by the ropes, and Newton's 2nd law can be used to find the acceleration.

$\sum F_x = ma_x \qquad F_2 - F_1 = ma_x \qquad a = \dfrac{F_2 - F_1}{m}$

9. **Answer: B**
The horizontal component of the tension force vector is adjacent to the given angle, so it's equal to $T\cos(\theta)$.

10. **Answer: A, C**
The box, rope and person are not moving (and not accelerating) so the net force on each object is zero. The forces that two contact objects exert on each other are equal in magnitude (Newton's 3rd law). The friction force acting on the box is equal and opposite to the tension force acting on the box, which is equal to the tension in the rope, which is equal to the force exerted on the rope by the person and the force exerted on the person by the rope, which is equal and opposite to the friction force exerted on the person by the floor.

11. **Answer: D**
When rope 1 is cut, the tension in rope 1 disappears (it drops to zero) so there is no upwards force acting on the 2 kg block. After rope 1 is cut the two blocks are in free fall and accelerate downwards at g, 9.8 m/s² because there is no upwards force acting on the system of two blocks. If each block is accelerating down at g then the net force on each individual block must only be the weight force acting on that block, so the tension force exerted on each block by rope 2 is zero. If there was any tension in rope 2 then the 2 kg block would accelerate downwards at a greater rate than g and the 5 kg block would accelerate downwards at a smaller rate than g (or even accelerate upwards if the tension was greater than the weight of the 5 kg block).

12. **Answer: 4 N**
One way to solve this is to first find the acceleration of the system of the two blocks, which is also the acceleration of the 2 kg block, and use that to find the tension force on the 2 kg block:
System of two blocks: $\sum F_x = ma_x \qquad (20\text{ N}) = (2\text{ kg} + 8\text{ kg}\,12)a_x \qquad a_x = 2\text{ m/s}^2$
2 kg block: $\sum F_x = ma_x \qquad T = (2\text{ kg})(2\text{ m/s}^2) \qquad T = 4\text{ N}$
Another way to solve this is to set up Newton's 2nd law for each block and get a system of two equations and two unknowns, T and a_x, and then use substitution to solve for T:

2 kg block: $\sum F_x = ma_x \qquad T = (2\text{ kg})a_x \qquad a_x = \dfrac{T}{2\text{ kg}}$

8 kg block: $\sum F_x = ma_x \qquad (20\text{ N}) - T = (8\text{ kg})a_x = (8\text{ kg})\dfrac{T}{2\text{ kg}} \qquad T = 4\text{ N}$

13. **Answer: 4.7 m/s²**
The forces acting on the block are: a tension force with a rightwards horizontal component and an upwards vertical component, an upwards normal force, a downwards weight force, and a leftwards kinetic friction force. The magnitude of the kinetic friction force depends on the normal force, $f_k = \mu_k F_n$, which can be found by applying Newton's 2nd law to the vertical direction first. Then the friction force is included in Newton's 2nd law for the horizontal direction. The weight force is greater than the vertical tension component so a_y is zero.
$\sum F_y = ma_y \qquad F_n + T_y - F_g = ma_y \qquad F_n + (40\text{ N})\sin(20°) - (5\text{ kg})g = (5\text{ kg})(0) \qquad F_n = 35.3\text{ N}$
$\sum F_x = ma_x \qquad T_x - f_k = ma_x \qquad (40\text{ N})\cos(20°) - (0.4)(35.3\text{ N}) = (5\text{ kg})a_x \qquad a_x = 4.7\text{ m/s}^2$

14. **Answer: T_1 = 226.3 N, T_2 = 113.2 N**
The block is suspended and not moving (not accelerating) so the net force on the block is zero in the vertical and horizontal directions. Newton's 2nd law can be applied to each direction to get a system of equations, and T_1 can be solved for and then substituted into the horizontal equation.
$\sum F_y = ma_y \quad T_{1y} - F_g = ma_y \quad T_1\sin(60°) - (20\text{ kg})g = (20\text{ kg})(0) \quad T_1 = 226.3\text{ N}$
$\sum F_x = ma_x \quad T_2 - T_{1x} = ma_x \quad T_2 - T_1\cos(60°) = ma_x \quad T_2 - (226.3\text{ N})\cos(60°) = (20\text{ kg})(0)$
$T_2 = 113.2\text{ N}$

15. **Answer: T_1 = 200 N, T_2 = 157.2 N, T_3 = 42.9 N**
One way to solve this is to apply Newton's 2nd law to each block to get a system of equations with several unknowns, and then solve the system of equations. Or we can apply Newton's 2nd law to the system of three blocks to find the acceleration of the sytem, which is also the acceleration of each block, and use that in Newton's 2nd law for the bottom block and then the middle block. The tension in the top rope (rope 1) is equal to the 200 N force applied to it.
System of three blocks: $\sum F_y = ma_y \quad (200\text{ N}) - (14\text{ kg})g = (14\text{ kg})a_y \quad a_y = 4.49\text{ m/s}^2$
Bottom block: $\sum F_y = ma_y \quad T_3 - (3\text{ kg})g = (3\text{ kg})(4.49\text{ m/s}^2) \quad T_3 = 42.9\text{ N}$
Middle block: $\sum F_y = ma_y \quad T_2 - T_3 - F_g = ma_y \quad T_2 - (42.9\text{ N}) - (8\text{ kg})g = (8\text{ kg})(4.49\text{ m/s}^2)$
$T_2 = 157.2\text{ N}$

Answers - Pulley Systems

16. **Answer: B**
The direction of the tension force in a rope is parallel to the rope, so when a rope bends around a pulley the direction of the tension force changes as the rope changes direction. The magnitudes of the tension forces at both ends of the rope are equal only if the pulley is ideal (massless and frictionless).

17. **Answer: A, C**
An ideal pulley is assumed to be frictionless and massless (so it has no rotational inertia). An ideal pulley does not have to rotate at a constant speed and it can rotate in either direction.

18. **Answer: C**
When a rope passes around an ideal pulley (which is frictionless and massless) then the tension force at each end of the rope is the same. We assume that any change in the tension force at one end of the rope is instantly transmitted to the other end of the rope.

19. **Answer: A**
We assume that the rope does not change length so the displacement of each end of the rope is the same and the magnitude of the displacements of block 1 and block 2 are equal, but the directions are different.

20. **Answer: B**
If a pulley is not ideal and has rotational inertia (mass), we cannot assume that the tension in the rope on each side of the pulley is the same. However, the tension on each side may be the same if the system is not moving and the two blocks have the same mass.

21. **Answer: B**
We assume that the rope does not change length so the speed of each end of the rope must be the same. If the speeds were not the same the rope would have to get longer or shorter over time. We also know that the magnitude of the displacement of each end of the rope is the same for any period of time, so the speed of each end must also be the same.

22. **Answer: D**
If we analyze the blocks and rope separately, there is a downwards weight force and upwards tension force on block 2. That tension force is equal to the rightwards tension force acting on block 1 because the pulley is idea. Since there is no friction on block 1, the rightwards tension force is the only horizontal force so it accelerates to the right and block 2 accelerates downwards. If we treat the two blocks and the rope as a single system, there is one external force acting on the system in the direction of the "rope axis", which is the weight force on block 2. That force causes the system to accelerate.

23. **Answer: C**
We assume that the rope does not change length so the acceleration of each end of the rope must be the same. This is the same concept as both ends of the rope having the same displacement and the same speed, which are only based on the assumption that the rope does not change length and do not depend on the pulley being ideal or the tensions in the rope being the same on either side of the pulley.

24. **Answer: A**
One way to solve this is to treat the two blocks and rope as a single system and apply Newton's 2nd law in the direction of the "rope axis" where the direction of the acceleration is the positive direction:

System, rope axis: $\sum F = ma \quad F_{g2} - F_{g1} = (m_1 + m_2)a \quad m_2 g - m_1 g = (m_1 + m_2)a \quad a = \dfrac{m_2 g - m_1 g}{m_1 + m_2}$

Another way to solve this is to apply Newton's 2nd law to each block separately to get a system of two equations and use the fact that the tension on each block is the same and the accelerations are the same. If we treat the direction of the acceleration of each block as the positive direction:

Block 2: $\sum F_y = ma_y \quad F_{g2} - T = m_2 a \quad m_2 g - T = m_2 a \quad T = m_2 g - m_2 a$

Block 1: $\sum F_y = ma_y \quad T - F_{g1} = m_1 a \quad T - m_1 g = m_1 a \quad m_2 g - m_2 a - m_1 g = m_1 a$

$m_2 g - m_1 g = m_1 a + m_2 a \quad a = \dfrac{m_2 g - m_1 g}{m_1 + m_2}$

25. **Answer: 58.8 N**
This can be solved by applying Newton's 2nd law to each block to get a system of two equations and two unknowns, the tension in the rope and the acceleration (both of which are the same for both blocks). If we treat down as the positive direction for block 1 and up as the positive direction for block 2:

Block 1: $\sum F_y = ma_y \quad F_{g1} - T = m_1 a \quad m_1 g - T = m_1 a \quad a = g - \dfrac{T}{m_1}$

Block 2: $\sum F_y = ma_y \quad T - F_{g2} = m_2 a \quad T - m_2 g = m_2 a \quad T - m_2 g = m_2\left(g - \dfrac{T}{m_1}\right) \quad T = 58.8\text{ N}$

26. **Answer: 6.2 m/s²**
The magnitude of the acceleration of blocks 1 and 2 is the same, and the magnitude of the tension force acting on each block is the same. Each block has a weight force that acts vertically downwards. Block 1 also has a normal force acting on it which is perpendicular to the incline surface, and a kinetic friction force acting down the incline (parallel to the incline). We can apply Newton's 2nd law to each block, choose down as the positive direction for block 2, up and parallel to the incline as the positive direction for block 1, and use substitution.

Block 2: $\sum F_y = ma_y \quad F_{g2} - T = m_2 a \quad m_2 g - T = m_2 a \quad T = m_2 g - m_2 a$

Block 1: $\sum F_\perp = ma_\perp \quad F_n - F_{g\perp} = m_1(0) \quad F_n - m_1 g\cos(30°) = m_1(0) \quad F_n = m_1 g\cos(30°)$

$\sum F_\parallel = ma_\parallel \quad T - F_{g\parallel} - f_k = m_1 a \quad T - m_1 g\sin(30°) - \mu_k m_1 g\cos(30°) = m_1 a$

Substituting T: $m_2 g - m_2 a - m_1 g\sin(30°) - \mu_k m_1 g\cos(30°) = m_1 a \quad a = 6.2\text{ m/s}^2$