Chapter 4 - Newton's Laws of Motion

Physics 206

For any problems where you are given a variable/symbol and a value for that variable, make sure to solve the problem symbolically first. Your final answer should then only contain the variables that you are given values for in the problem, constants that appear on the equation sheet and numbers like 2 or π.

Group 1 Problems:

Problem 1: In the following figures and situations, identify all the action-reaction pairs. If you can, attempt to identify the directions of each of the forces.

(a) In Problem 6 there is an Atwood's Machine. Use the situation where $m_A > m_B$ so that the system stays in that configuration.

(b) In Figure B, there is friction between the big block and the surface and between the small block and the big block. The blocks are being lowered at a constant speed.

(c) In Figure C, a person is using their hand to hold a block against a wall by pushing up and into the block.

(d) In Figure D, there is friction between the bottom block and a table, as well as between the blocks. The pulley is massless and a person is pulling the bottom block to the left with force F.

(e) In Figure E, there is friction between the block and the table. All three ropes are connected to a massless ring.

Figure B

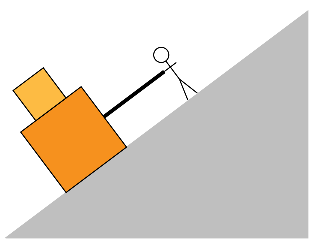


Figure C

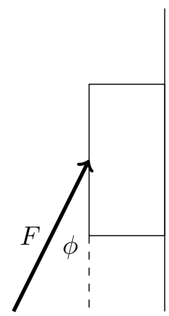


Figure D

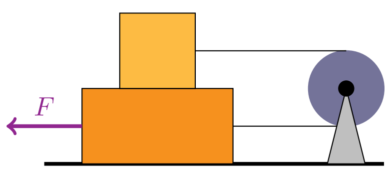
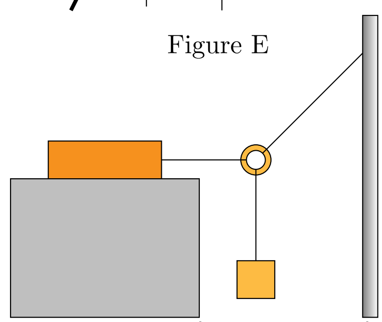


Figure E



Problem 2: Al and Bert stand in the middle of a large frozen lake (which you can treat as a frictionless surface). Al pushes on Bert with a constant force F for a time t. Bert's mass is m and Al's mass is M. Assume that both are at rest before Al pushes Bert.

(a) What is the speed that Bert reaches once Al has stopped pushing him?

(b) What speed does Al reach?

(c) Let the velocity of Al be $\vec{v}_A$ and the velocity of Bert be $\vec{v}_B$. What is $M\vec{v}_A + m\vec{v}_B$?

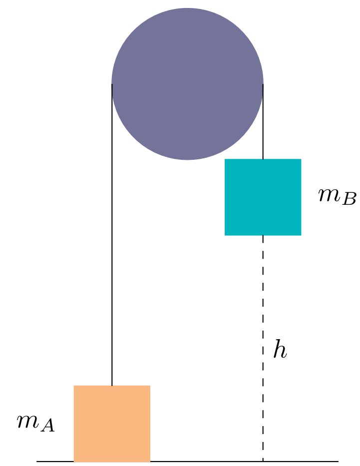
Problem 3: Two blocks are in contact on a horizontal, frictionless surface. Block 1 has a mass of m and block 2 has mass of M. If an external force F pushes on block 1 what is the magnitude of the force that acts on block 2?

Problem 4: An $m = 5.00$ kg block sits on a horizontal frictionless surface. What horizontal force is necessary to accelerate the block from $v_0 = 0.00$ to $v = 10.0$ m/s over a distance of $\Delta x = 4.00$ m? What if it was 5.00 m/s instead of 0.00 m/s?

Problem 5: A man with mass m_M is standing on a scale while riding in an elevator. What does the scale read when:
(a) The elevator is stationary.
(b) The elevator is moving upward with constant velocity v.
(c) The elevator is accelerating upward with constant magnitude of acceleration a
(d) The elevator is accelerating downward with constant magnitude of acceleration a
(e) The elevator is accelerating horizontally with constant magnitude of acceleration a
(f) The elevator is accelerating at an angle of 30 degrees from the upwards vertical with constant magnitude of acceleration a. This is more like the Willy Wonka elevator.

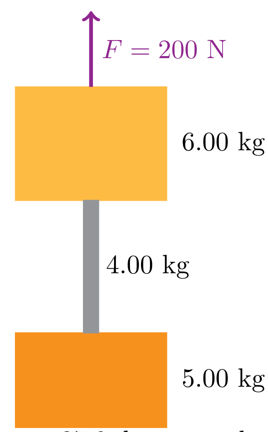
Group 2 Problems:

Problem 6: The device to the right is called Atwood's Machine, a common setup in introductory physics courses and labs. The pulley is massless and frictionless. For all parts of this problem assume when the system is released, Box A is at rest in contact with the table.
(a) If $m_B < m_A$ what is the normal force the table exerts on Box A?
(b) If $m_B = m_A$ what is the normal force the table exerts on Box A?
(c) If $m_B > m_A$ what is the velocity of box B when it hits the table?



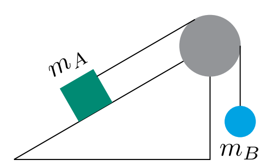
Problem 7: The two blocks in the figure are connected by a heavy uniform rope with a mass of 4.00 kg. An upward force of 200 N is applied to the 6.00 kg block as shown.

(a) Draw three free-body diagrams: one for the 6.00 kg block, one for the 4.00 kg rope, and another one for the 5.00 kg block. For each force, indicate what body exerts that force.
(b) What is the acceleration of the system?
(c) What is the tension at the top of the heavy rope?
(d) What is the tension at the midpoint of the rope?



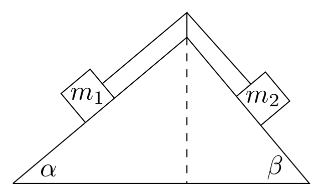
Problem 8: An 8.00 kg block sits at rest at the base of a 10.0 m long, frictionless ramp that makes a 37.0 degree angle with the horizontal.
a) What constant horizontal force must be applied to the block in order to move the block up the ramp at a constant speed?
b) What constant horizontal force must be applied to the block in order to accelerate the block up the ramp so that the speed of the block is 25.0 m/s at the top of the ramp?

Problem 9: A block of mass $m_A = 15.0$ kg is placed on a frictionless ramp that makes a $\theta = 30$ degree angle with the horizontal. The block is connected by a light rope over a massless pulley and attached to a ball of unknown mass, m_B, that hangs vertically. Remember to use the fact that if the rope is light and the pulley is massless, the tension is the same at all points along the rope.
(a) What mass of the ball will hold the system at rest?
(b) What range of masses for the ball will allow the block to slide up the ramp?
(c) What range of masses for the ball will allow the block to slide down the ramp?



Problem 10: A 90.0 kg rock climber is ascending a mountain side. For safety, the climber must have a rope attached to their harness that is secured to the belayer below. As the climber goes up, they clip the rope into carabiners anchored into the rock. Assume the mountainside is perfectly vertical. The rope has a max force rating of 5000 N. However, the rope doesn't just instantly catch the climber; instead, climbing ropes are designed to stretch a bit before fully catching the climber. Assume that this stretching occurs over a period of 0.200 seconds and that the force is applied uniformly over the stretching distance. Assuming there is no slack in the system, the climber would fall twice the distance that they are above the previous carabiner (such that if they are 5.00 meters above the previous carabiner, they would fall 10.0 meters). This climber is particularly reckless and continues climbing above the latest carabiner without clipping into more.
a) What is the max height above the latest carabiner that they can climb before they would be in danger of the rope breaking with a fall?
b) Why is it important that the rope stretches when catching a climber? Explain this in terms of Newton's laws.

Group 3 Problems:
Problem 11: The two boxes in the figure are connected by a rope that passes over a frictionless peg. Both boxes slide on a frictionless incline, as shown in the figure. Assume that the tensions acting on both blocks are the same.
(a) What does the ratio of m_1 to m_2 have to be for the acceleration of the blocks to be zero.
(b) What is the acceleration of the blocks and the tension in the rope if $\alpha = 40.0$, $\beta = 50.0$, $m_1 = 8.00$ kg and $m_2 = 10.0$ kg.



Problem 12: An object of mass m is at rest in equilibrium at the origin. At $t = 0$ a new force $\vec{F}(t)$ is applied that has components

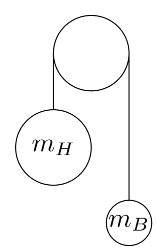
$$F_x(t) = k_1 + k_2 y$$
$$F_y(t) = k_3 t$$

where k_1, k_2 and k_3 are known constants. Calculate the position $\vec{r}(t)$ and velocity $\vec{v}(t)$ vectors as functions of time. Note that the y in $F_x(t)$ is the y-position as a function of time. It is not a constant.

Problem 13: A beekeeper developed what they thought was a great way to harvest the perfect amount of honey. They built an Atwood's machine which is shown in the figure to the right. As the bees bring back nectar, the mass of the hive increases based on the following equation:

$$m_H(t) = m_B \left(1 + 5.00 \times 10^{-4} e^t\right)$$

where the mass is in μg. If at $t = 0$ the hive is at rest, and it takes 20.0 seconds to fall 15.0 m where the beekeeper catches it, what is the speed of the hive when the beekeeper catches it? Is this invention a good idea?



Problem 14: A physics professor, equipped with a rocket backpack, steps out of a helicopter at an altitude of $H = 500$ m with zero initial velocity. The professor and all her equipment have a mass, $m_p = 90.0$ kg. For a time $t_1 = 4.00$ s, she falls freely. At that time, she fires her rockets and slows her speed using a constant upward thrust of $F_t = 1100$ N until her speed reaches $v_f = 5.00$ m/s. At this point, she adjusts her rocket engine controls to maintain that speed until she reaches the ground. Neglect air resistance for this problem.
a) On a single graph, sketch her acceleration, velocity and position as functions of time. Take upward to be positive. On a separate graph, sketch the force due to gravity and the thrust as a function of time again where upward is positive.
b) What is her speed after a time t_1 has elapsed?
c) What is the duration of her slowing-down period?
d) How far does she travel while slowing down?
e) How much time is required for the entire trip from the helicopter to ground?
f) What is her average velocity for the entire trip?