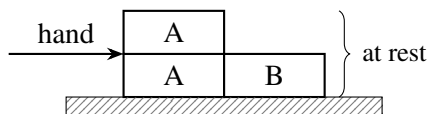
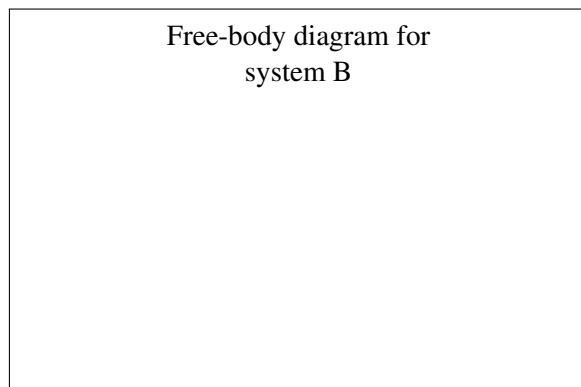
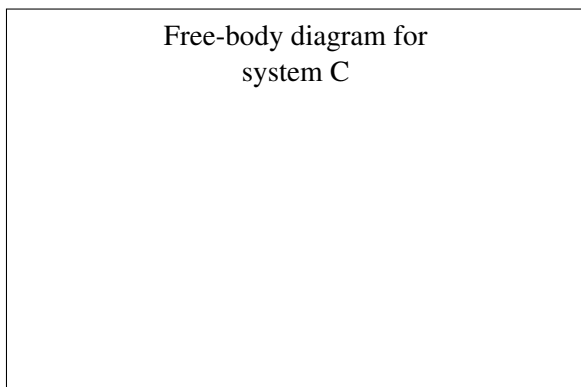


I. Static friction: bricks that do not move

Three identical bricks, each of mass 2.5 kg, sit on a table as shown. The hand pushes horizontally on system A, but the bricks *do not move*. The coefficient of static friction between the bricks and the table is $\mu_s = 0.50$. Let system C be all three bricks. (Use $g = 10 \text{ m/s}^2$.)



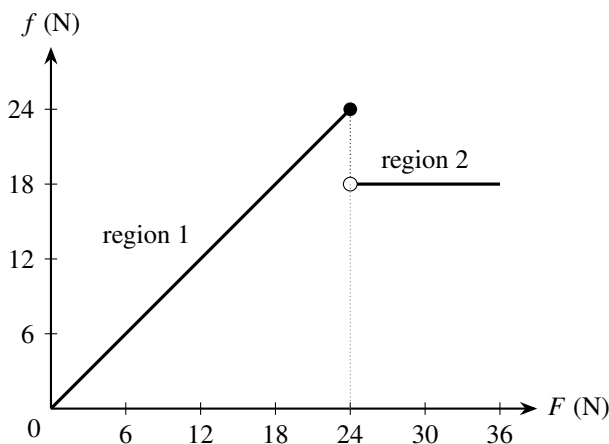
- A. Compare the *net force* (magnitude and direction) on system A, on system B, and on system C. Explain how you arrived at your comparison.
- B. Draw free-body diagrams for system C and for system B. Label each force by identifying the type of force, the object on which it is exerted, and the object exerting it.



- C. The hand pushes on system C with a force of 10 N. What is the magnitude of the friction force exerted on system C by the table? What is it if the push is 25 N? In each case, is the friction force equal to $\mu_s N$? Explain.
- D. What is the largest push for which the bricks stay at rest? What happens if the push is slightly larger than this?
- E. Consider the following discussion between two students.
Student 1: "The normal force on the bricks is 75 N and $\mu_s = 0.50$, so the friction force on the bricks is 37.5 N no matter how hard the hand pushes, as long as they don't move."
Student 2: "I disagree. The friction force just matches the push. It can't be bigger than the push or the bricks would start moving backward."
 With which student, if either, do you agree? Explain your reasoning.
- F. Identify the Newton's third law (action-reaction) partner of the friction force that the table exerts on system C. On which object is the partner force exerted? Why is it not included on your free-body diagram for system C?
- G. When the hand pushes with 10 N, can you determine the friction force exerted by the table on system A and on system B separately? Explain what you can and cannot conclude.

II. From static to kinetic friction

A 4.0 kg block rests on a horizontal table. Starting from rest, a hand pushes horizontally on the block with a force F that is slowly increased from zero. The graph shows the magnitude of the friction force f exerted on the block by the table. (Use $g = 10 \text{ m/s}^2$.)



- A. In region 1 the block does not move. How does the magnitude of the friction force compare to the magnitude of the push? What is the net force on the block? What kind of friction acts here?
- B. What is happening at the point where the graph drops, and what is the physical meaning of the 24 N value? What kind of friction acts in region 2?
- C. Use the graph to determine the coefficient of static friction and the coefficient of kinetic friction between the block and the table.
- D. The block is now sliding. Draw a free-body diagram for the block while the hand pushes with a constant 30 N. Then determine the block's acceleration.

Free-body diagram for
the block (pushed with 30 N)

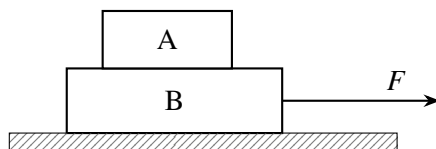
- E. While the block is sliding to the right, the hand's push is changed. Describe the motion that results (including the acceleration, if any) if the push becomes:
 - (i) 18 N
 - (ii) 10 N

For case (ii), what happens after the block comes to rest? What is the friction force at that point?

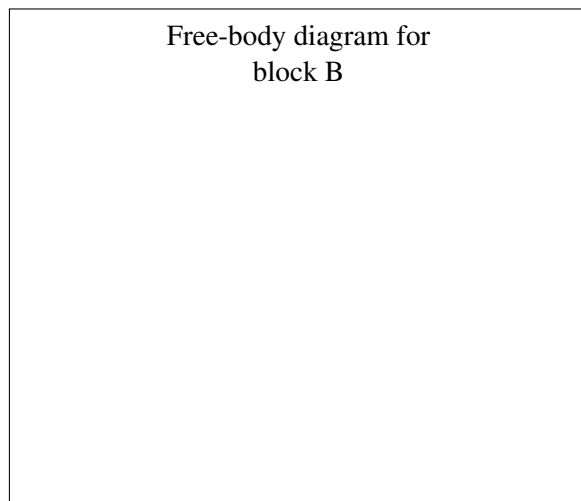
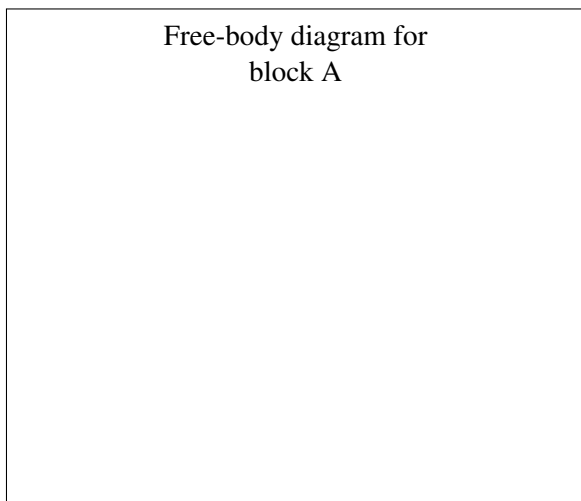
- F. A second identical 4.0 kg block is placed on top of the first, and the pair is pushed as one object, again starting from rest. On a copy of the graph (extend the axes as needed), sketch (dashed) what you would expect. Explain how the peak value and the value in region 2 each change.

III. Friction between stacked blocks

Block A (2.0 kg) rests on block B (3.0 kg), which sits on a horizontal table. A rope pulls horizontally on block B with a constant force $F = 20$ N. The blocks move to the right, and block A *does not slip* on block B. The coefficient of static friction between A and B is 0.40; the coefficient of kinetic friction between B and the table is 0.20. (Use $g = 10 \text{ m/s}^2$.)



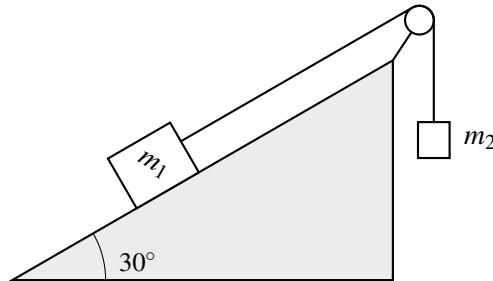
- A. Compare the accelerations (magnitude and direction) of blocks A and B. Explain.
- B. Draw separate free-body diagrams for block A and block B. Label each force with its type, the object on which it is exerted, and the object exerting it.



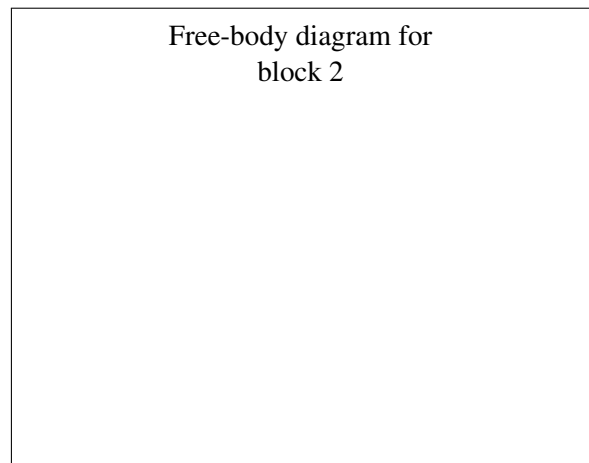
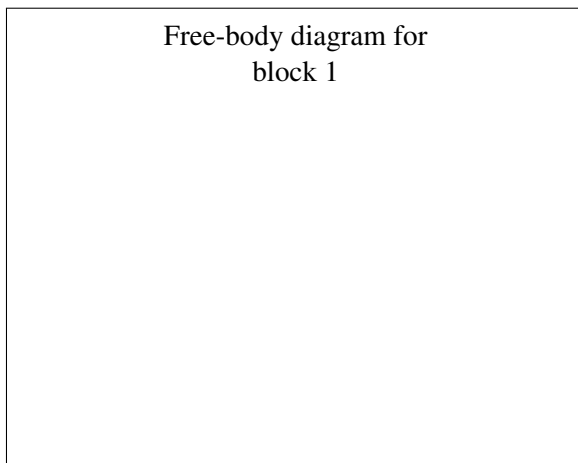
- C. Block A speeds up toward the right. Which object exerts the horizontal force on A that makes it accelerate? In what direction does this force point? Is it static or kinetic friction? A student says, "Friction always opposes motion, so the friction on A must point left." How would you respond?
- D. Identify all of the Newton's third law force pairs in your diagrams by marking each member of a pair with matching small "×" symbols. What criteria did you use?
- E. Determine the magnitude of: (i) the acceleration of the blocks, (ii) the friction force on B by the table, and (iii) the friction force on A by B. Is (iii) equal to $\mu_s N$ for block A? Explain.
- F. Find the largest value of F for which A does not slip on B. If F were larger than this, describe how the motions of A and B would compare, and say what kind of friction would then act between A and B.

IV. Friction on an incline

Block 1 ($m_1 = 4.0$ kg) sits on a rough incline at 30° . A light rope runs over a light, frictionless pulley to a hanging block 2 of mass m_2 . Between block 1 and the incline, $\mu_s = 0.40$ and $\mu_k = 0.30$. (Use $g = 10$ m/s², $\sin 30^\circ = 0.50$, $\cos 30^\circ \approx 0.87$.)



- A. Suppose $m_2 = 1.0$ kg and nothing moves. Draw free-body diagrams for block 1 and block 2. Does the friction force on block 1 point up or down the incline? How can you tell?



- B. Now m_2 is increased slowly until block 1 is just about to slide up the incline. How has the direction of the friction force changed? Determine the range of values of m_2 for which the blocks remain at rest. (Consider both limits: block 1 about to slide down, and about to slide up.)
- C. Block 2 is replaced with $m_2 = 5.0$ kg and released from rest. Is the tension in the rope equal to $m_2 g$? Explain. Determine the acceleration of the blocks and the tension in the rope.
- D. Later, while block 1 is moving up the incline, the rope breaks. Describe the motion of block 1 from that moment on. When it momentarily comes to rest, will it stay at rest or slide back down? Support your answer with a calculation, and if it slides, find its acceleration.