Free-body Diagrams

There will be an exam on Friday. This exam will be

1. easy, because I know all of the material.
2. fun, because taking tests is the best!
3. interesting, because I want to learn how much I know.
4. all of the above.

ANS: **4**—All of the above.

A locomotive engine pulls a series of train cars. Which is the correct analysis of the situation?

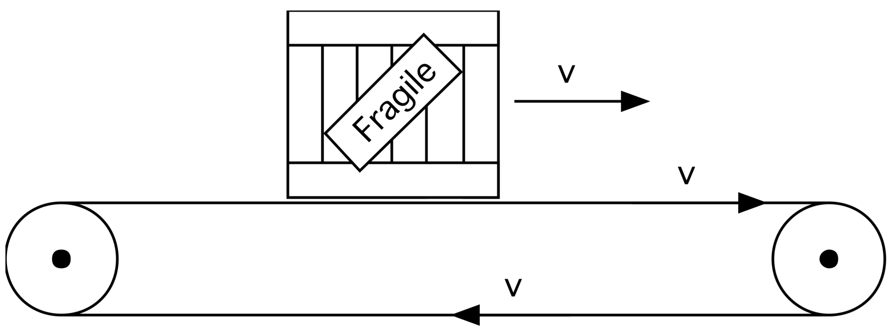
1. The engine pulls forward slightly harder on the cars than the cars pull backward on the engine.
2. Action always equals reaction, so the cars pull backward on the engine just as hard as it pulls forward on the cars. Therefore, there is no motion.
3. The engine starts moving the cars by initially pulling on the cars more than the cars pull back on the engine.
4. The engine and cars exert equal forces on each other, but the frictional force on the engine is forward and large while the backward frictional force on the wagons is small.
5. The engine can pull the cars forward only if it weighs more than the cars.

ANS: **4**—The frictional force on the engine is greater than on the rest of the cars.

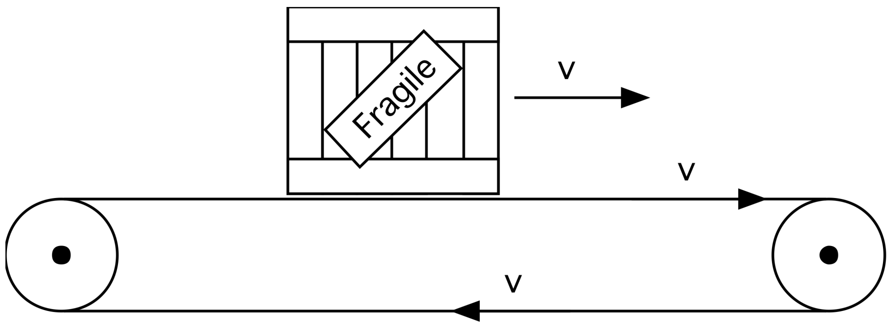
The force that pushes a train forward is the static friction force pushing forward on the wheels of the engine car. There will be various drag and friction forces pushing backward on the engine and other cars. As long as the forward-pushing static friction force is greater than all of the backward forces, the train will accelerate forward.

A crate is moving to the right on a conveyor belt without slipping. The conveyor belt maintains a constant speed. The force of friction on the crate is

1. to the right
2. zero
3. to the left



A crate is moving to the right on a conveyor belt without slipping. Then the conveyor belt speeds up, gradually increasing the speed of the box to the right.

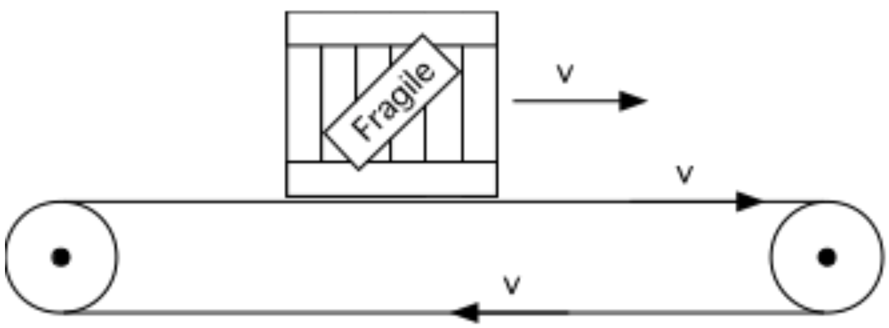


The force of friction on the crate is

1. to the right
2. zero
3. to the left

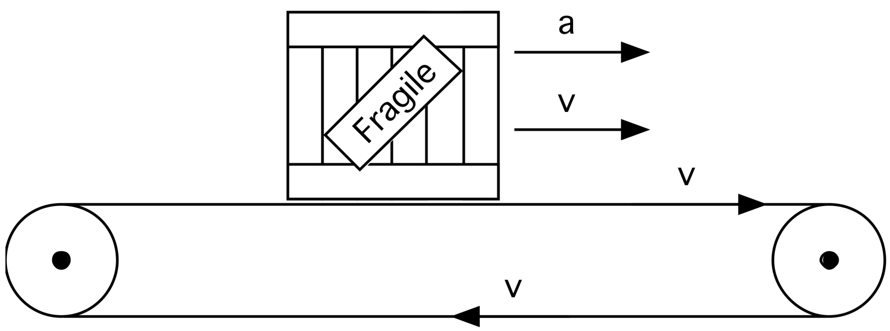
A crate is moving to the right on a conveyor belt without slipping. The conveyor belt is slowing down. The force of friction on the crate is

1. to the right
2. zero
3. to the left

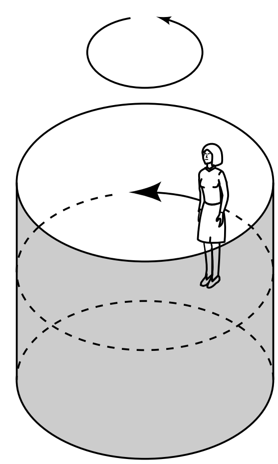


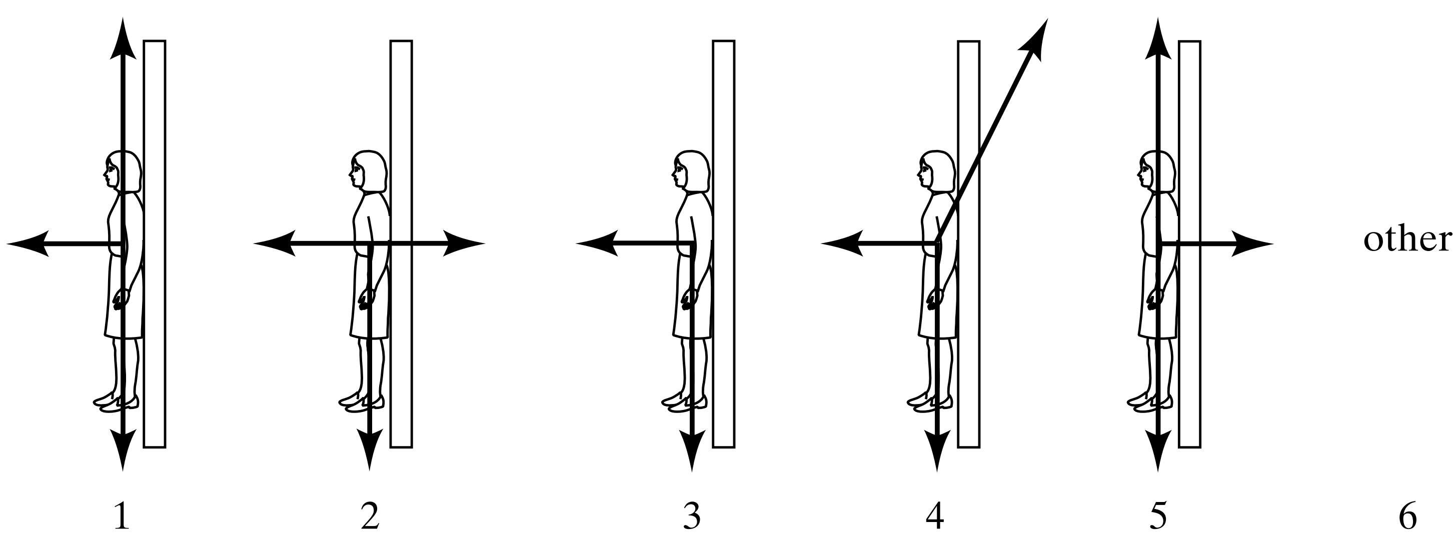
A crate is moving to the right on a conveyor belt without slipping. Then the conveyor belt speeds up, gradually increasing the speed of the box to the right. The force of friction on the crate is

1. kinetic
2. static
3. There is no friction acting on the box



Consider a “Barrel of Fun” ride, in which riders stand inside a cylindrical “cage” that begins to spin. As it speeds up, riders start feeling pressed back against the wall of the ride. When it turns fast enough, the floor of the ride is removed and the riders are no longer standing on anything. The diagram below shows one such rider who finds herself stuck with her back to the wall. Which diagram correctly shows the forces acting on her?





ANS: The correct answer is diagram **1**.

First, let's consider the vertical forces on the person. There will certainly be a downward (gravitational) force on her. However, she does not accelerate in the vertical direction, so there is no net force on her in the vertical direction. Therefore, there must be an upward force of static friction holding her up. That static friction must lie in the plane of contact between her and the wall, so we find that choices #2, #3, and #4 are wrong.

She is in contact with the wall, so there must be a (normal) force of contact between her and the wall. Unless she is tied or glued to the wall, this force must be directed to the left (the wall pushes on her). Therefore, #5 cannot be the correct answer.

So is **1** the correct answer, or must there be another choice? First, let's examine her motion. She is moving at constant speed around a circular path, so there must be a radial acceleration pointing toward the center of the circle. Therefore, there must be a net force pointing toward the center of the circle. Luckily, the force of the wall pushing on her always provides just such a force. It also always points toward the center of the circle.

Warning: A common error when working with her free-body diagram is to conclude that since she does not *accelerate away from the wall*, there must be no net force in the horizontal direction. But she does accelerate horizontally—toward the center of the barrel.

Consider the previous “Barrel of Fun” question. Can the barrel ever turn fast enough that friction is not needed to hold the rider in place?

1. Yes
2. No

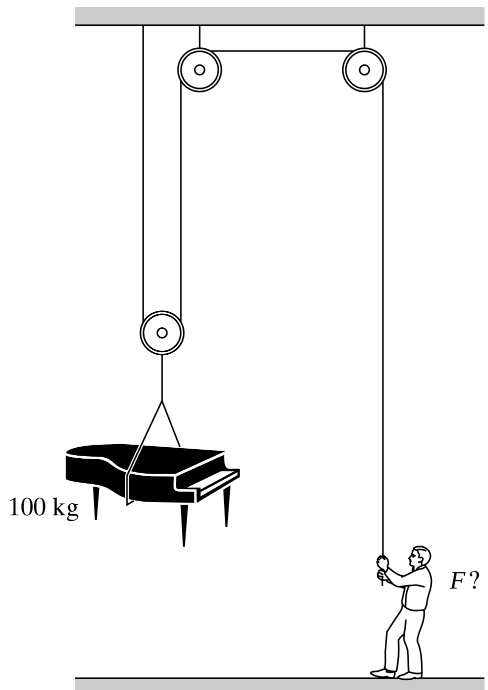
ANS: **2**—the barrel can *never* turn fast enough so that friction is not needed to hold the rider in place.

From the free-body diagrams in the previous question, there must always be an upward static friction force to hold her (vertically) in place against gravity.

What, then, does the speed of the ride have anything to do with the problem? Her radial acceleration is v^2/R, where R is the radius of the barrel. To keep her moving in a circle, the wall must push on her with a "normal" force equal to mv^2/R, where m is her mass. Finally, the static friction force on her is $f_s \leq \mu_s N = \mu_s mv^2/R$.

At low speeds, this force is small and cannot hold her up against her weight. At higher speeds, $\mu_s mv^2/R$ can be much greater than her weight, and static friction will easily hold her up. Notice because m appears in the expression for her weight and for the maximum static friction force, the mass does not matter. The safe speed that will hold people in the barrel is the same regardless of their mass.

A piano mover raises a 100 kg piano at a constant rate using the frictionless pulley system shown here. With how much force is he pulling on the rope? Ignore friction and assume $g = 10$ N/kg. (The tension in the rope is the same everywhere.)



1. 2000 N
2. 1000 N
3. 500 N
4. 100 N
5. 50 N
6. Impossible to determine

ANS: The correct answer is diagram **1**.

First, let's consider the vertical forces on the person. There will certainly be a downward (gravitational) force on her. However, she does not accelerate in the vertical direction, so there is no net force on her in the vertical direction. Therefore, there must be an upward force of static friction holding her up. That static friction must lie in the plane of contact between her and the wall, so we find that choices #2, #3, and #4 are wrong.

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