Rotational Dynamics

You don't really understand something until you understand it in more than one way.

—Marvin Minski

A bowling ball slides along a highly polished (basically frictionless) lane without rotating. Then it reaches a section with friction, at which point it quickly starts to rotate until it rolls without slipping. Does the linear speed of the ball's center of mass change as it starts to roll?

1. Yes, it increases
2. Yes, it decreases
3. No, it remains constant

A bowling ball slides along a highly polished (basically frictionless) lane without rotating. Then it reaches a section with friction, at which point it quickly starts to rotate until it rolls without slipping. Does the ball's mechanical energy change?

1. It decreases while sliding
2. It decreases while rolling
3. It decreases during both periods
4. It only decreases during the transition
5. No, it remains constant throughout
6. Other

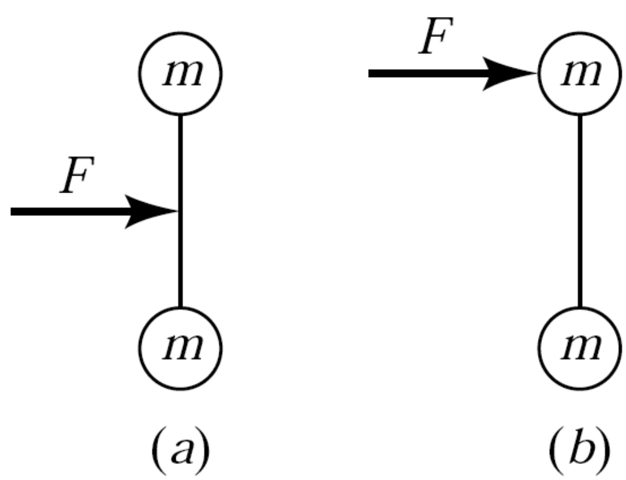
Can an object experience a net force without experiencing a net torque?

1. Yes (provide example)
2. No (explain why not)

Can an object experience a net torque without experiencing a net force?

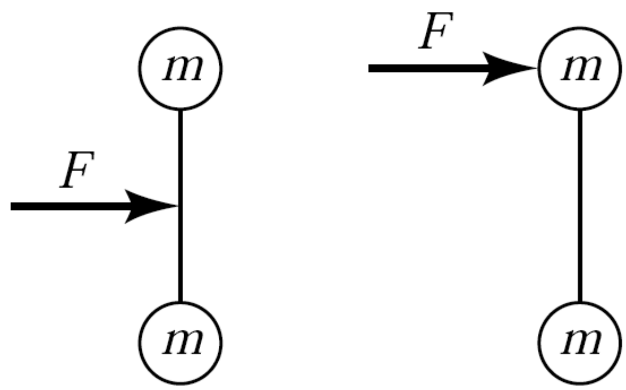
1. Yes (provide example)
2. No (explain why not)

A force F is applied to a dumbbell for a time interval t, first as in (a) and then as in (b). In which case does the dumbbell acquire the greater center of mass speed?



1. a, in center
2. b, on edge
3. makes no difference
4. depends on the moment of inertia

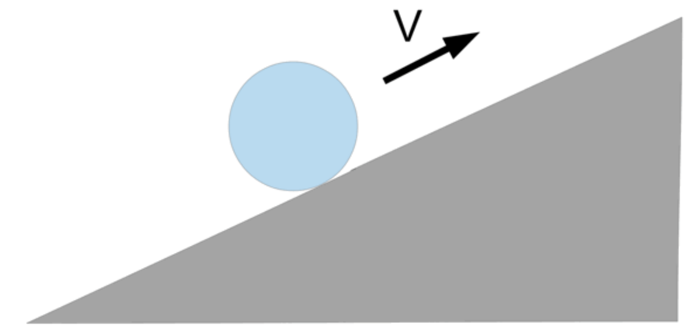
A force F is applied to a dumbbell for a time interval t, first as in (a) and then as in (b). In which case does the dumbbell acquire the greater energy?



(a) (b)

1. a, in center
2. b, on edge
3. makes no difference
4. depends on the moment of inertia

A ball rolls up a hill without slipping.



What direction is the force of friction on the ball at the point of contact?

1. Uphill
2. Downhill
3. Normal
4. It depends on how fast the ball is moving
5. There is no friction in this situation

Two buckets hang from the ends of a rope laid over a pulley. Initially, everything is at rest. For an idealized pulley, the heavier bucket would fall, but this is a real pulley with a mass! (The shaft is still frictionless) Can the pulley mass be made large enough to prevent the heavier bucket from falling?

1. Yes
2. No, but it can be slowed down
3. No, the system will fall as fast as before
4. Need more information (specify!)

With regard to the same set-up, in which end of the rope is the tension larger?

1. The one attached to the heavier bucket
2. The one attached to the lighter bucket
3. Tension is the same in both

Warmup Question

You want to push open a heavy door. Where should you push it to make it open most easily: near the hinge (rotation axis), the middle of the door, or far from the hinge? Explain your answer.

ANS: You want to push it farthest from the hinge. It will take a certain amount of torque to provide the necessary angular acceleration to open a door in the usual way. If there is friction in the hinges, it will require even greater torque.

To provide this torque most easily, i.e. with the least force possible, you want to apply your pushing force perpendicular to the door, far from the hinge. This provides a large lever arm. The necessary applied force is equal to the required torque divided by the lever arm.

Warmup Question

The Dude sends his bowling ball down the lane toward the geometrically arranged pins at the far end. The ball slides without rolling at first on the highly polished maple floor, but it eventually catches and thereafter rolls without sliding. Discuss what happens to the ball as it rolls in terms of forces, various energies, and momentum.

ANS: While the ball is sliding on the highly polished floor, there is no rolling motion and hence no rotational kinetic energy. All of the ball's kinetic energy will be translational. We know that there is no friction force between the floor because if there were, this force would exert a net torque around the ball's (horizontal) central axis. The existence of a net torque would require an angular acceleration around the axis, which implies the rotational motion will change. (It will start rotating.)

When the ball "catches," we know that the ball does, in fact, begin to roll. Therefore there must be a net torque on the ball. The only force that would cause this torque is friction. The angular acceleration implies that the ball's rotational velocity is increasing, meaning its rotational kinetic energy is increasing. There is no source of additional energy on the ball, so its translational kinetic energy must, in turn, decrease. Another way to look at this is to realize that friction between the ball and floor will cause the ball to slow down. As the ball's rolling motion increases, its translation speed decreases until the translation speed of the center of mass equals the product of the ball's radius and angular velocity ($v = r\omega$). At that point, there is no more friction between the ball and floor, so the angular and translational velocities of the ball are constant.

Warmup Question

After the Dude’s ball is rolling, and just before it hits the pins, describe the instantaneous velocity at the very highest point on the ball and estimate the speed there. Hint: estimate the data your need about a typical bowling ball’s behavior from this video, but ignore the curve.

ANS: The speed of the ball at the top will be twice the center-of-mass speed of the ball. This is because the speed of the ball at the top is $v = r\omega$ greater than the speed of the ball at the center. The center of the ball, in turn, is $v = r\omega$ greater than the speed of the bottom of the ball. Since the ball is rotating, the bottom of the ball is always instantaneously at rest with respect to the floor ($v_{\text{bottom}} = 0$. Therefore, $v_{\text{top}} = 0 + r\omega + r\omega = 2r\omega = 2v_{\text{center}}$.

A bowling lane is 60feet long, and it takes $2 - 3$seconds to roll down the lane. Therefore, the ball's speed is $20 - 30$ft/s, and the tangential speed of the top of the ball is $40 - 60$ft/s.