Forces*

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Abstract

Forces and friction effect the motion and changes of motion of objects, like small robots.

An object in motion, or at rest, will not change its state of motion unless a force is applied. This resistance to changes in motion is called **inertia**. To be clear, a change in motion is not just beginning to move from a stop. Slowing down, speeding up, and changing direction are all changes in motion. The only way to change a object's motion is to apply a force to that object. A book slid across a table only comes to a stop because of the frictional forces acting on it. Inertia is proportional to mass, so a more massive object is more difficult to move or stop than a lighter one, even on a frictionless surface. This module will consider forces and friction, which both act on an object's inertia.

Just as a book slides until a force opposes its motion, a disc will spin until its rotation is opposed by some force. This property is aptly named **rotational inertia**. One of the most common applications of rotational inertia is shown in . Many children's toys use rotational inertia. In friction-drive cars, the child pushes the car forward several times to set an internal flywheel in motion. When the car is put down, the flywheel is still spinning and the car moves. This is an interesting way to store energy – in kinetic, rather than potential form. A flywheel could conceivably be used to store energy to keep small robot operating after its motors were required to be shut off. Rotational inertia is also used to avoid changes in motion for such objects as record players, where it is important to maintain rotation at a constant speed.

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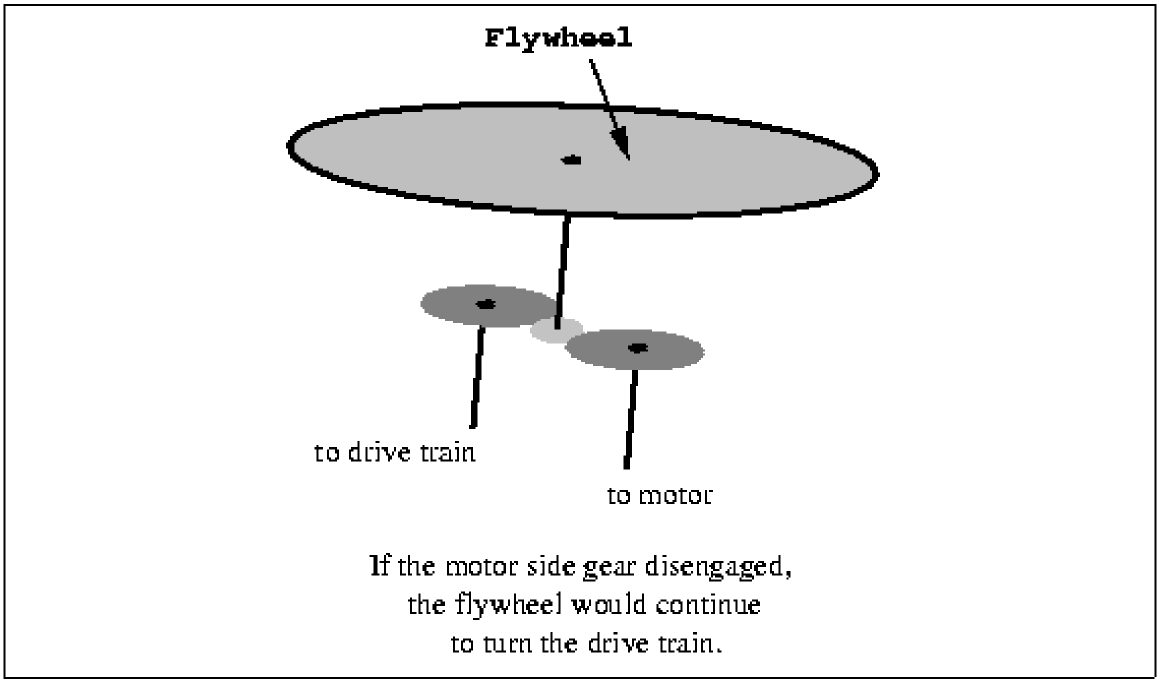

Figure 1: Flywheel

1 Force

Whether a force is the push of a motor or the pull of gravity, the important characteristics are the magnitude and direction of the force, and the mass and previous state of motion of the object being affected. By pushing on a moving car, one can either cause it to gain speed or come to a stop, depending on which direction the force is applied, and that same force applied to a feather would be expected to more drastically affect the motion of the feather.

It is common practice to determine the expected changes in motion that an object will experience due to a particular force with the aid of a **free body diagram**. A diagram can tell us at a glance in which direction we would expect an object to accelerate or decelerate. A free body diagram shows all of the forces acting on an object, even if their effects are balanced out by another force. We will use free body diagrams to consider different situations involving the lamp that you find at your lab station (Figure 2).

One force that always acts on the lamp is gravity. This familiar force would accelerate the lamp downward toward the center of the earth **if** left unchallenged. However, when the lamp is placed on a table it does not move downward because the table holds it up. The lamp is pushing down on the table and the table is pushing up on the lamp. This pair of forces is an action-reaction pair: equal and opposite forces acting on two different objects in contact. The reaction force from the table is called the **normal force** because this force is oriented normal (perpendicular) to the surface of the table. The arrows representing the forces are labeled. The symbols over the labels remind us that the forces are vector quantities and that the direction in which the force is applied is important. The length of the force vector should be proportional to their magnitudes.

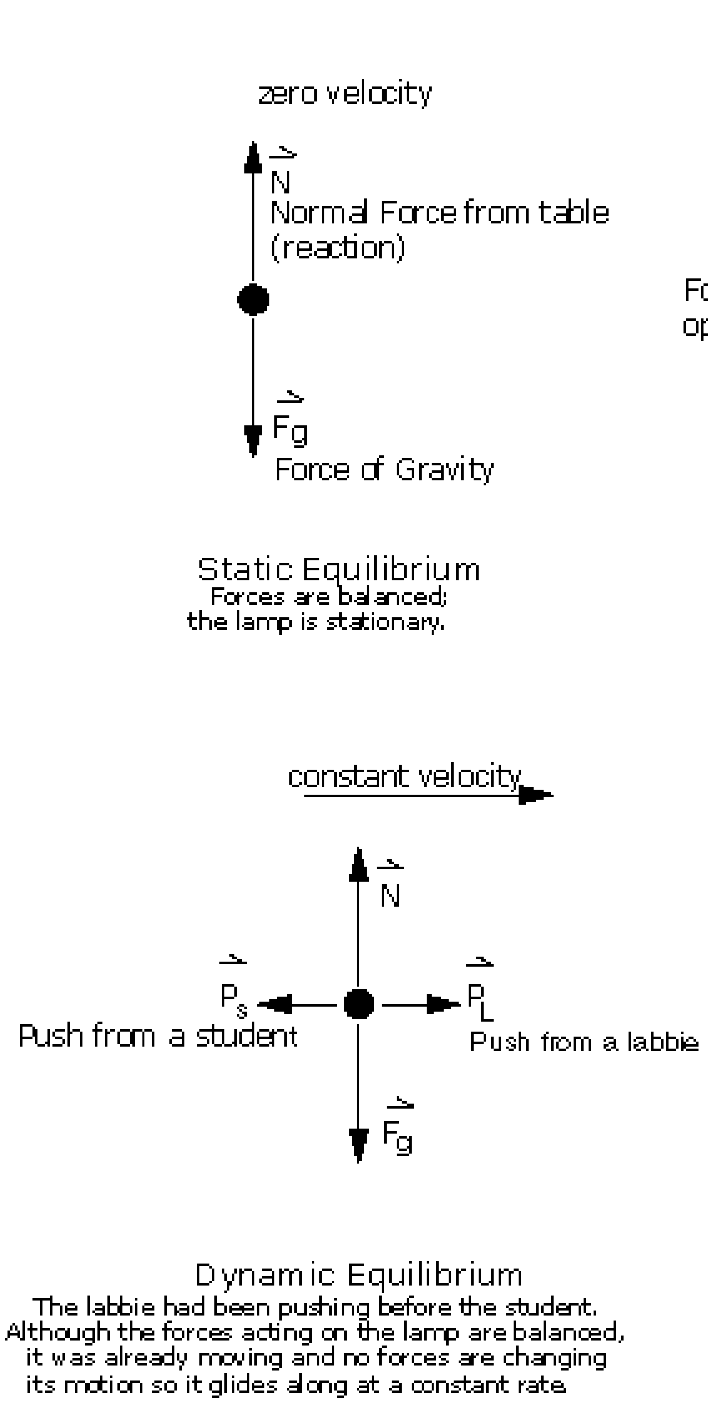

Figure 2: Free Body Diagrams

In Figure 2 the lamp was represented by a simple dot. We assumed that the lamp was rigid and that a downward force applied at one particular spot on the lamp would yield the same result as a similar downward force applied at a different place on the lamp. Actually, in order for a force of equal magnitude and direction to affect an object's motion in the same manner it must be applied along the same line of action as the original force (see Figure 3). If the original force had been a tug on a string tied to the lamp, then it makes sense that grabbing the string at a different distance away from the lamp to tug should not make a difference provided that the direction and magnitude do not change.

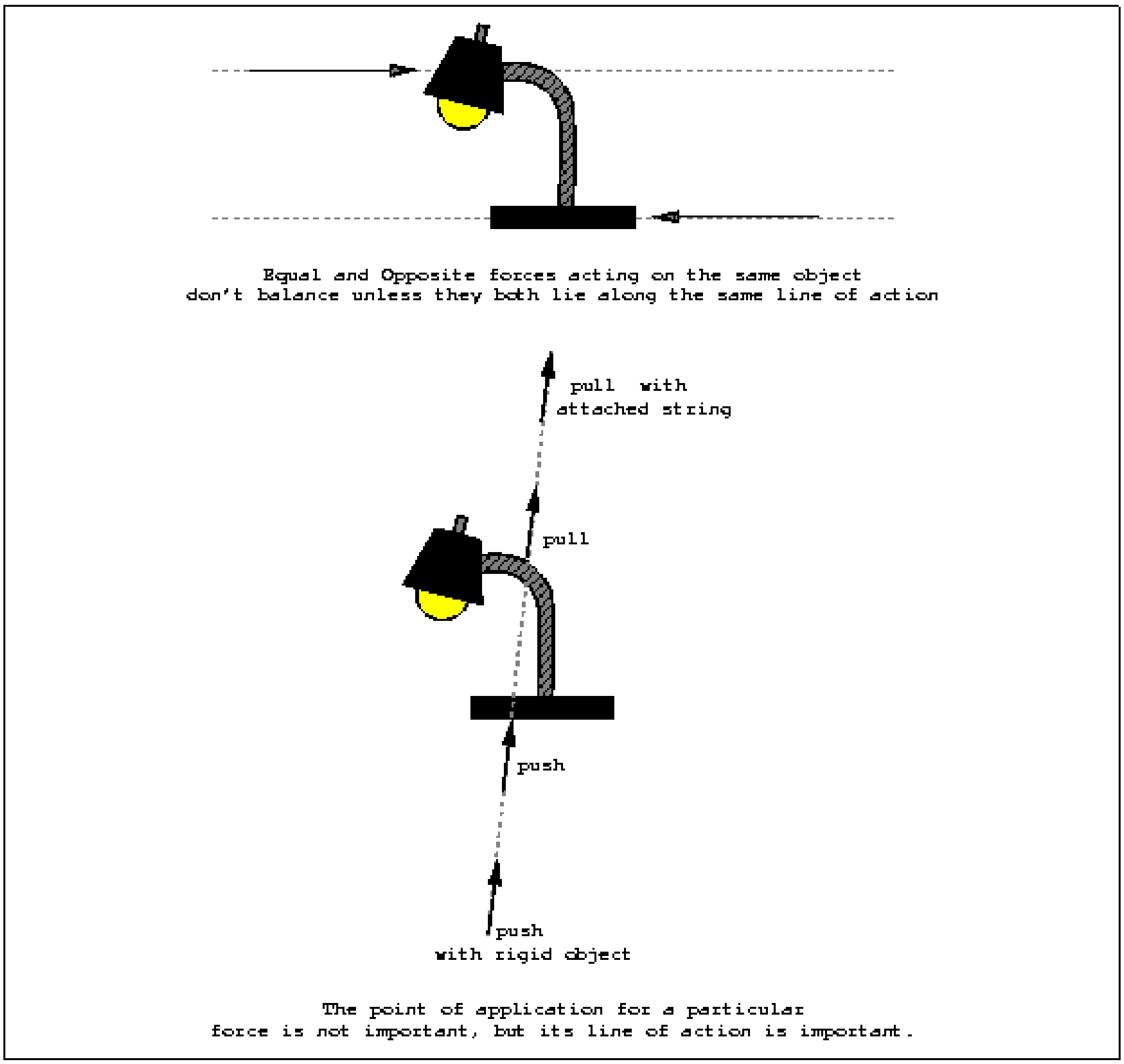

Figure 3: Line of Action

2 Friction

The normal force from the table's surface is a reaction force **only**. Without the downward force on the table from the object resting its weight on the surface, the normal force does not exist. This type of behavior is also descriptive of frictional forces.

Friction is opposition to motion, so if nothing is trying to move there will be no friction. However, friction will be present when motion is attempted, even if the object is not yet moving. There are two different types of friction: static, which acts before the object begins to move, and dynamic, which acts after the object begins moving. **Static friction** is usually stronger than **dynamic friction**.

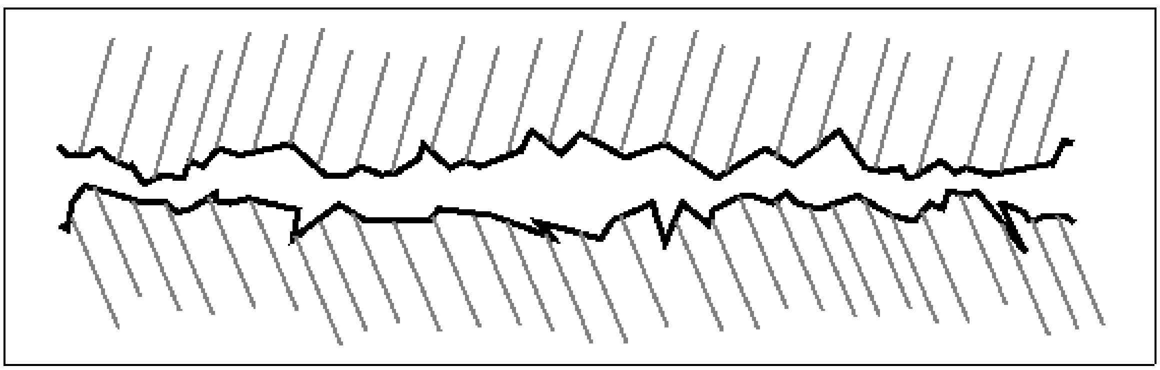

Figure 4: "Close Up" of surfaces in contact

Friction occurs because the surfaces in contact are **not** smooth. The small ridges on the different surfaces catch, and in order for the objects to move, these ridges must be broken off or the object must ramp up and over the obstructions. By adding a lubricant between the two layers, it is possible to "float" one layer high enough to miss some of the obstructions to motion. At an atomic level, cold joints may form where the atoms from one object's surface may form weak bonds with the atoms on the surface of the other object. These bonds must also be broken in order for the object to move. All of this resistance to motion is called **friction**. Friction is very important because it not only inhibits motion, friction also makes motion possible.

Most, but not all, small robots (such as those built in the Rice University course ELEC 201, Introduction to Engineering Design) will probably be wheeled vehicles, and without friction those wheels would just spin in place without moving the robot anywhere. In order to increase the friction between the wheels and the game board one might use wheels made of a different material or add a rubber band around the wheel's circumference. Friction is not desirable in all cases. When it comes to axles spinning inside of holes in beams or gears rubbing up against beams or even gears pushing against each other, friction can cause two identically constructed gear trains to behave differently. Friction can even render the whole assembly ineffective. For example, in one design, a worm gear in a drive train created so much friction that more of the drive motor's effort went towards overcoming friction than actually driving the robot.