Opposing Forces

Introduction

The word *force* is a common term in our everyday speech. It is used in situations such as being "forced" to do something (usually against one's will) or about market "forces" that drive the economy. These uses, while correct according to a dictionary, are not what is meant when the discussion turns to science. For science, the term force refers to an agent that, if unfettered by equally opposing forces, will cause a net acceleration in the object upon which it is acting. This was the conclusion of Isaac Newton over three hundred years ago when he developed his three laws of motion that described how forces operate.

It is the ability of a force to cause accelerations that is normally how it will get studied. The force will be allowed to act on an object all by itself. By measuring the acceleration of the object and its mass, one will get a measure of the force using Newton's Second Law, which relates force to mass and acceleration.

Fig. 1: Baby standing (*whitehouse.gov*)

However, it is not usually via accelerations that we, as humans, first encounter forces in our lives. Our first interactions are normally in the form of counteracting forces that exactly offset one another to keep an object stable. At least, this is the goal when, as a baby, we tried to hold our head upright or to stand on our own. At an early age, unbalanced forces can be bad things. Until we get some reasonable motor control and coordination, we must be content with just offsetting the inherent forces on us, i.e. gravity, in order to stay fixed in a position.

Of course, this does not end in childhood. If you are sitting while you are reading this, you are still trying to offset a series of forces to keep your body in the position it is in. Furthermore, the interior of your body is having to push outward with a force of about 103 KPa to keep the enormous weight of air that is above you from crushing (accelerating) you inward. All in all, it is good that you learned the skill to offset forces very early on.

Opposing Forces versus Newton's Third Law

Before proceeding to the activity, though, let us discuss one issue that commonly confuses people: Newton's Third Law, which states for every force, there is an equal and opposite force. This law often leads folks to believe that there is no such thing as a net force, since forces always come in pairs that cancel. This is not the case, as the law only refers to the presence of forces and not to the objects upon which the forces act.

When we state that an object will accelerate under the influence of a net force, we are only summing up the forces acting on the object and not the forces of the object on its surroundings. For instance, an idealized car that is accelerating down the road has several forces acting upon it. There is the force of the road upward on the car. There is the force of gravity on the car that is pointing downward toward the center of Earth. There is the frictional force of the road on the wheels of the car that is pushing the wheels forward. The first of these two forces are opposing forces that cancel each other. Gravity pulling down on the car is equal to the force with which the road pushes up on the car, and hence, the car does not sink into the ground or levitate in the air. The frictional force of the road on the wheels, though, is unbalanced, and thus, the car accelerates down the road.

At the same time as this is occurring, each one of these forces has its equal and opposite "twins", as detailed by Newton. But these twin forces are of the car on its surroundings, not vice-versa. The car is pulling up on Earth via gravity with just as much force as Earth is pulling down on the car. The car is pushing down as hard on the ground with the same force as the ground is pushing up on the car. And finally, the wheels of the car are pushing back on the road with the same force as the road is pushing the wheels forward.

These are the equal and opposite forces that Newton discusses in his Third Law. All of them are of the car on the world around it. They cannot cancel the forces on the car, as they do not operate on the car. Thus, the car is able to accelerate. These reaction forces might also cause accelerations, but if they do, it will be on the objects upon which they are acting. For instance, the frictional force of the tires that points backward along the road is accelerating the road in that direction. We do not notice it, though, because the road is attached to the entire planet, which has a mass that is many orders of magnitude greater than that of the car. While the force is great enough to provide a measurable acceleration in the car, it is not large enough to cause one in Earth.

Vectors

Living in a one-dimensional world would have one distinct advantage over our three dimensional one: physics problems would be very simple because objects could only move backward and forward along a line. To specify the position, velocity, acceleration, force, etc. would be as simple as just stating a number, as the presence of a positive or negative sign tells direction relative to some reference point. For those of us living in the three-dimensional world (or 11-dimensional, if you talk to string theorists), describing these quantities is a little more complicated. We have to develop a coordinate system (usually Cartesian, spherical, or cylindrical) with orthogonal axes and then state the values or relevant equations along all three axes.

For most of the work that is done in an introductory physics class, one can simply change the perspective such that only two of the dimensions are important. For example, a ball rolling over the surface of table is confined to the two dimensions of the tabletop and does not require that we keep track of its position normal to this surface. To describe vector quantities in two dimensions, we can either use Cartesian or polar coordinates. Figure 2 shows a diagram of a point that is 4 meters to the east and 5 meters to the north of the origin. These would be the values of the Cartesian coordinates for this position vector of this point, and are usually written as (x, y) = (4 m, 5 m). However, we could have also stated the position (in polar coordinates) vector as 6.4 meters from the origin at an angle of 51 degrees above east. This would be written as (r, θ) = (6.4 m, 51°).
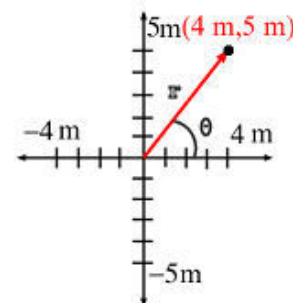

Fig. 2: Vector example

Normally, one would pick a coordinate system and stick with it throughout the investigation of a system. There are times, though, when the information you are given is in terms of the other coordinate system. Converting between these two systems is quite easy with the use of trigonometry. If you know the Cartesian coordinates, you can calculate the polar coordinates using the equations:

$$r = \sqrt{x^2 + y^2}$$
$$\theta = \tan^{-1}(y/x)$$

If you know the polar coordinates, you can calculate the Cartesian coordinates by applying the equations:

$x = r \cos \theta$
$y = r \sin \theta$

Biological Systems

Everything in nature involves the interaction of forces and life has evolved an amazing array of systems that balance forces. These

systems specialize in various ways to ensure reproductive fitness for the organisms we see. Being able to define and measure these independent forces allows biologists to investigate how particular selective pressures have affected numerous organisms, showing patterns of convergent evolution and common ancestry (homology). Organismal behaviors that we find fairly common-place require evolutionary modifications to ensure their fitness within particular

environments (Fig. 3) and even organisms that we don't think of as being active must interact with a multitude of forces (Fig. 4).
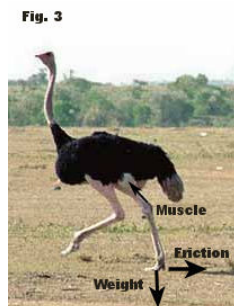
Procedure

In this lab, we are going to study opposing forces while we get some practice converting from polar to Cartesian coordinates, and vice versa. We will do this using a round force table. This device consists of a metal ring with four masses attached to it via very thin strings. When the ring is placed in the center of the table and the masses are allowed to hang over the edge of the table using the moveable pulleys, gravity pulls down on the masses, thus applying forces on the ring along the strings. If the sum of these forces on the ring is zero, then there is no net force on the ring and it stays in the center. If the sum is not zero, then a net force pulls the ring away from the center when the pin is pulled out of the table. Since the acceleration due to gravity is the same on all of the masses, the differences in the forces on the various strings depend only upon the hanging mass attached to it. Thus, a state of equilibrium is initially reached when the vector sum of the masses (amount of mass at the stated angles) is zero.

Fig. 5: Force table and masses

The activity sheet lists three sets of three masses that are to be hung at the listed angles on the table. You will need to mathematically calculate what mass at what angle needs to be added to each set of masses so that equilibrium is reached. You will then verify that your answer is correct by setting up each situation on the table and removing the pin to see if it remains at equilibrium.

Opposing Forces 3

Name:

Instructor:

Set	Mass 1	Mass 2	Mass 3	Calculated Mass and Angle	Measured Mass and Angle
1	50 gm at 90°	100 gm at 180°	100 gm at 270°		
2	50 gm at 45°	50 gm at 120°	100 gm at 240°		
3	50 gm at 60°	100 gm at 120°	100 gm at 300°		

1. How close is your calculated mass and angle to the measured mass and angle? Was it easy finding exactly one mass and angle that offset the forces?

2. What are some of the random errors that occurred in your measurements?

3. What are some of the systematic errors that occurred in your measurements?

4. How large do you believe is the amount of discrepancy caused by each systematic error?