Newton's Laws I

PES 1150 General Physics Lab I

Purpose of the experiment

- To answer the question "Why do objects move?".
- Explore Newton's 2nd Law and see how force, mass, and acceleration relate to each other.
- Explore Newton's 3rd Law and see how the direction of the action-reaction pairs relate over time.
- To understand the vector nature of force.
- To understand the difference between a scalar sum and a vector sum.
- To verify the vector nature of force graphically and mathematically via the component method.
- FYI

^{FYI} The very first bomb dropped by the Allies on Berlin during WWII killed the only elephant in the Berlin Zoo.

Background

Force, Mass and Acceleration

Previously, you have studied *kinematics*, which is the branch of physics that describes *how* objects move. By understanding the quantities of position, velocity and acceleration, you are able to describe an object's motion. Kinematics does not say *why* objects move, just how they move. In this lab, we will look at the branch of physics called *dynamics*. Dynamics relates the cause of motion (forces) to a description of how objects move (acceleration). For dynamics, we will need to discuss three quantities, mass, acceleration and force, in order to answer the question "Why do objects move?".

You should already be familiar with acceleration. If you are not, then a good definition for acceleration is:

<u>Acceleration:</u> the rate of change with respect to time of an object's velocity. An acceleration would include speeding up, slowing down, or changing direction.

Basically, anything that causes an object to differ from straight line, steady speed motion is an acceleration. Dynamics addresses two other quantities that are related to acceleration. The first is mass:

<u>Mass:</u> the quantity of matter an object possesses. Mass has the property of inertia, which is the behavior of an object to move in a straight line at a steady speed when left alone. Mass is a resistance to acceleration.

The second is force:

Force: A push or a pull. An influence that causes objects to accelerate.

With these concepts under our belt, we can discuss the principles of dynamics, called Newton's Laws of Motion.

When an object is left alone without any influences on it, the object will move in a straight line at a steady speed. This type of motion is referred to as *uniform motion*, or since an object's velocity defines both its speed and direction, it is also known as *constant velocity motion*. This is the natural, default motion of an object.

In order to change an object's behavior from moving on a straight line at a speed that does not change, it must be affected by an outside influence. As we saw in the previous section, we call these influences *forces*. Thus, forces are what cause an object to deviate from straight line behavior (i.e. the object will turn or change direction), from constant speed behavior (i.e. go faster or go slower), or both. When a single force acts on an object, the object will no longer be able to follow its natural, default motion.

However, if two or more forces act on an object, the possibility exists that the forces can cancel each other's effects and therefore leave the object to persist in its default motion. While at first glance, it might seem improbable that forces would cancel exactly, this happens all the time. As examples, consider a book sitting still on a table, or the skydiver example in the 'Analysis' section of this lab.

Therefore, there are two ways in which an object can persist in uniform motion: (1) if <u>no</u> <u>forces</u> at all act on the object or (2) if all the forces <u>completely cancel</u> each other. In either case, no *net* force acts on the object. Mathematically, Newton's first law is stated as:

$$\sum \vec{F} = 0 \Leftrightarrow \Delta \vec{v} = 0$$
 (Newton's First Law)

This means that if there is no net force (the vector sum of the forces is zero), then the object does not change velocity. The double arrow also means that the reverse is true too. If an object exhibits straight line, steady speed motion, then there can be no net force acting on it.

It is very difficult in practice to have an object on which there are no forces whatsoever acting on it. There is always going to be friction, air resistance or a gravitational tug influencing the object's motion. The very fact that it is difficult to isolate an object from all outside forces lead to the long held (thousands of years!) belief that that natural state of an object is at rest. The main culprit here was friction. If friction slowed every object you ever saw to rest, and you didn't know what friction was, you'd hold that erroneous belief too! So, since we can't have an object with absolutely no forces acting on it, we will do the next best thing. In Part I of this lab, we are going to carefully and systematically arrange things so that the forces that are acting on a wheeled cart (in this case, gravity, friction and a normal force) exactly cancel. And we will see that, indeed, the resulting motion of the object will be its natural, default and uniform motion.

Newton's Second Law

How does a cart change its motion when you push and pull on it? You might think that the harder you push on a cart, the faster it goes. Is the cart's velocity related to the force you apply? Or does the force just *change* the velocity? Also, what does the mass of the cart have to do with how the motion changes? We know that it takes a much harder push to get a heavy cart moving than a lighter one.

A Force Sensor and an Accelerometer (both of which are integrated into the Smart Cart) will let you measure the force on a cart simultaneously with the cart's acceleration. The total mass of the cart is easy to vary by adding masses. Using these tools, you can determine how the net force on the cart, its mass, and its acceleration are related. This relationship is Newton's second law of motion.



Figure 1: Set up for testing Newton's 2nd Law.

You may have learned this statement of Newton's third law: "To every action there is an equal and opposite reaction." What does this sentence mean?

Unlike Newton's first two laws of motion, which concern only forces on individual objects, the third law describes an interaction between two bodies. For example, what if you pull on your partner's hand with your hand? To study this interaction, you can use two Force Sensors. As one object (your hand) pushes or pulls on another object (your partner's hand) the Force Sensors will record those pushes and pulls. They will be related in a very simple way as predicted by Newton's third law.

The *action* referred to in the phrase above is the force applied by your hand, and the *reaction* is the force that is applied by your partner's hand. Together, they are known as a *force pair*. This short experiment will show how the forces are related.



Figure 2: A force pair between lab partners.

Nearly every force encountered in everyday life obeys Newton's 3rd Law. Therefore, nearly all forces are members of a force pair. Given a force, it is very easy to figure out what force is the reaction. To do this, simply switch the ordering of the objects. For example, consider a book sitting on a table. The table exerts an upward force on the book, and we call that "the force of the <u>table</u> on the <u>book</u>". So what is the reaction force? It is simple, just switch the ordering of the objects. The reaction force is "the force of the <u>book</u> on the <u>table</u>". Be careful,

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because you might be tempted to say the reaction force is the weight of the book. This is incorrect. Why? Because the other object in the weight force pair is the Earth itself! So this force pair is "the weight of the <u>book</u> due to the <u>Earth</u>" and "the weight of the <u>Earth</u> due to the <u>book</u>". Again, simply switch the ordering of the objects. (Yes, the book does pull up on the Earth. So why doesn't the Earth move?)

There is a big distinction between Newton's second law and Newton's third law. The second law deals with the forces acting on a single object. The vector sum of these forces produces an acceleration that affects that single object's motion. In contrast, the third law concerns forces that act *between* two objects. *The forces described by Newton's third law act on two different objects and never on the same object*. The force caused by the first object affects the second object's motion, and the force caused by the second object affects the first object's motion. This distinction is very important to keep in mind when trying to understand and apply Newton's laws of motion.