ESA21
Environmental Science Activities for the 21st Century

Newton’s Second Law

Introduction

There are two ways to study the dynamics of a system in which there is motion. One of these is to study the kinematics of the system to see if there is any acceleration. If there is an acceleration, then this implies that there is a net force on some part of the system. If there is no acceleration, then this means that either there are no forces on the system, or that the forces within the system are all balanced.

The other way to study the system is from an energy standpoint. Energy can flow from potential to kinetic, or vice versa. Furthermore, energy can be exchanged between different parts of the system. If any object is giving energy to any other part of the system, then it must lose energy, either from its potential or kinetic energy.

Each view has its advantages and disadvantages. The energy view is nice mathematically, in that one is dealing with scalar quantities that are easy to handle. However, studying the energy does not really allow one to predict the direction of motion, only the magnitude. Studying the forces on the objects does allow this, but the mathematics involved in solving the motion is a little more complicated, in that one must use vectors. In this particular activity, we are going study a system using the force approach, while the next activity in this module will use the energy approach.

Newton

Sir Isaac Newton was not the first person to study and measure the motion of objects. As we stated in previous activities, there have been others like Aristotle and Galileo who did this before him. Nor was he the first person who tried to model motion with equations that would allow for predictive behavior. However, he was the first person to clearly state the basic laws of motion that allow us to analyze all systems. These three laws, known as Newton’s Laws of Motion, are

1. An object at rest or in a state of constant motion will remain in that state until acted upon by an unbalanced force.
2. The net force on an object is proportional to its acceleration, with the proportionality constant being called the mass, i.e. $m = F_{net}/a$.
3. For every force on an object, there is an equal and opposite force produced by the object on the source of the first force.

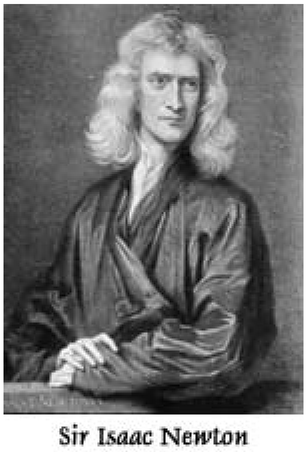

Fig. 1: Newton (*NASA*)

The first of these laws is a restatement of one of Galileo’s discoveries. While seemingly obvious, especially to us now, it is a very powerful statement. It says that an object that is noticed to be accelerating must have a net force acting upon it, even if the manner of the force is not readily noticeable. For instance, if one were to swing a rock on the end of a string in a circle, it would be obvious that the acceleration of the rock was due to the force exerted on it by the string, which is being accelerated by the hand holding it. However, what of an electron that is above the Earth’s atmosphere that also moves in a circular orbit? Since it is accelerating, we know that there must be some net force on it, even though there is nothing in contact with it (it turns out that the force operating on it is electromagnetism). Or what of a distant star that is going around in an elliptical orbit, seemingly by itself? We know that some other object must be applying a force on it, and by studying its motion, we might find its “neighbor” that is causing it to move thusly, even if its “neighbor” is a black hole that cannot be observed directly.

The second law is often quoted as only F=ma, but this simplified version misses out on the fact that this law defines the term mass, which is one of the more misunderstood terms in science. Many people confuse mass for weight, which is understandable since even scientists still persist in saying silly things like “one kilogram is equal to 2.25 pounds”. But a fuller description of Newton’s Second Law shows that the mass is the proportionality constant between the applied force and the resulting acceleration. Weight is merely the force that comes about because the gravitational attraction between two objects. It is only important to know this when this one type of force is present. Mass, on the other hand, is always an important factor, as it will determine the acceleration when any type of force is present.

Possibly more misunderstood is the last of Newton’s laws. It is used in many contexts where it should not, like economics, politics, and advertising, and is almost always used inappropriately. Even when it is used in the context of physics and the dynamics of objects, it is often misused. The reason is that the agents and receivers of the two forces involved in a situation are often left out, as when we state it merely as “For every force, there is an equal and opposite force.” If one does not realize that these two forces act on different objects, then they might not think that acceleration is never possible, as there will never be a net force if every force creates an opposing force of equal strength.

As an example, consider a person walking down the street. If we concentrate on the foot in contact with the ground, we will notice that it applies a force on the ground in the reverse direction that the person is travelling. According to Newton’s Third Law, the ground applies a force on the foot in the opposite direction. It is this “reaction” force that propels the body forward. However, we cannot forget about the force of the foot on the Earth. This force is propelling the Earth backward at the same time that the body is being propelled forward. Does the Earth really accelerate backward as the body goes forward? Yes, but not by any noticeable amount. This is because the Earth is so massive. While the forces on the person and the Earth are the same, the differences in their mass means that the acceleration of the Earth is infinitesimal compared to that of the person.

$$\mathbf{a_{Earth} = (m_{person}/m_{Earth})\ a_{person}}$$

Theory and Model

In this week’s activity, we are going to test these laws. In particular, we are going to test the validity of Newton’s Second Law using a quasi-frictionless cart attached to weights via a pulley (Figure 2). Because gravity is allowed to operate on the weights, they will supply a force to the string that is equal to $m_w g$. This force will be applied to the cart via the tension T in the string, which should accelerate under its influence. If there is no force lost in the pulley (frictionless pulley) or in the motion of the cart (frictionless surface), then the acceleration of the cart should be given by

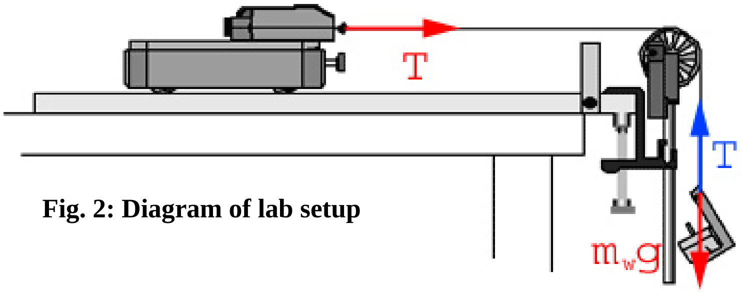

Fig. 2: Diagram of lab setup

$$a_{cart} = T/m_{cart}$$

The acceleration of the weights is a little more complicated, as gravity is acting down on the weights while the tension T in the string is pulling up on the weights. This gives

$$a_w = (T - m_w g)/m_w$$

By noting that the acceleration of the cart to the right is the same as the acceleration of the cart downward (and accounting for the fact that we take the acceleration to the right or up is positive), we can relate these two equations, and solve for the tension T in the string, i.e.

$$T = m_w m_{cart} g/(m_w + m_{cart})$$

Relating this back to the equation for the acceleration of the cart gives us

$$a_{cart} = m_w g/(m_w + m_{cart})$$

During the activity, we will use different masses of weights and measure the corresponding velocities of the cart. If friction is negligible, the plot of the velocity of the cart versus the time should yield a straight line of slope given by the above equation.

Procedure

Figure 2 shows the necessary set up for this activity. The actual equipment that you use for this will depend upon what is available at your institution. Some locations will have “frictionless” air tracks that have carts that move down the track on a cushion of air. Other locations will have carts that move along grooved tracks with low friction wheels. The method of measuring the carts velocity will also vary with locations. It is possible to measure the cart’s location using a pulley/photogate system that measures the how quickly the pulley turns and translates this into the object’s velocity. It is also possible to use a motion detector that bounces ultrasonic sound waves off of the cart as it moves. In any case, the instructions below should be followed, with any variations in methodology occurring in the process for measuring the cart’s velocity.

As seen in Figure 2, a constant force is applied to a dynamics cart to pull it across the track. The constant force will be provided by weights that are attached to a string that is suspended over a pulley. As gravity pulls these weights downward, it will pull the cart forward. This motion will be measured by a photogate built into the pulley, which will relay the information to our computer.

1. Make sure the track is level by adjusting any levelling screws. Level can be determined either by a) using a bubble level or b) placing the cart on the track to see if it moves in either direction without being pushed.

2. Measure the mass of the dynamics cart.

3. Connect one end of the string to the dynamics cart and the other to the hanging mass (start with a total of 50 grams). Place the cart on the track and run the string over the pulley. Pull the cart as far back along the track so that the mass hanger almost touches the pulley. Hold the hanger in place above the ground to prevent the system from moving.

4. Initiate any software that you will be using to measure the velocity of the cart.

5. Release the glider so it can be pulled by the falling mass hanger.

6. Stop the data recording just before the mass hanger reaches the floor.

7. Change the applied force (F = mg) by adding masses to the hanger. Repeat the data acquisition procedures above for total masses in 50 gram increments up to 250 grams. After this, add the bar weights to the cart and repeat the above procedure starting at 50 grams on the hanger

Data and Results

From the computer, we will have tables of times versus velocity for each run. Since the acceleration should be constant, a plot of velocity versus time should yield a straight line whose slope is the acceleration. For each run, you need to have a table of the data like below, plus a plot of velocity versus time and a measure of the slope of the line. When completed, answer the questions on the activity sheet.

ESA21: Environmental Science Activities

Activity Sheet
Newton's Second Law

Name:
Mass of the Cart = ________ gm

Velocity Data

Run 1		Run 2		Run 3		Run 4		Run 5	
Time	Velocity	Time	Velocity	Time	Velocity	Time	Velocity	Time	Velocity

Run 6		Run 7		Run 8		Run 9		Run 10	
Time	Velocity	Time	Velocity	Time	Velocity	Time	Velocity	Time	Velocity

After plotting each of these sets of data, calculate the acceleration from the best fit line of each graph

	R 1	R 2	R 3	R 4	R 5	R 6	R 7	R 8	R 9	R 10
$a_{measured}$										
$a_{theoretical}$										
% Difference										

1. How close are your theoretical accelerations to the measured values?

2. What are some possible characteristics of the experimental apparatus that are not accounted for in the model? Could these characteristics account for the differences between measured and theoretical accelerations?