Physics Project Preparation

Sometime during the semester, you will be asked to create and perform your own physics project. To prepare you (and your group) to do this, start by analyzing an existing experiment that you performed and answering the following leading questions. These questions will help you construct your own project. <u>The outline of the lab report you will generate from your own project is on the next page.</u>

Pick one experiment we performed as a class and answer the following:

1) What was the physical topic of the experiment? What were you trying to test or measure?

2) Based on your knowledge of physics, what did you anticipate will happen? Put differently, if you change A, what will happen to B? Explain why using physical principles.

3) What instruments did you use to test or measure your hypothesis?

4) How did you use these instruments to test your hypothesis?

5) Related to 4), what variable did you change to test your hypothesis?

6) What data did you collect? How did you organize this data?

7) How did you analyze the data to see if your hypothesis was correct, and you achieved the goal you set in step 1?

8) How can you improve the experiment you performed?

Lab Report Outline for Physics Project

Your lab report should contain the following information. You will be prompted for this in the project:

1) The goal(s) of the experiment- namely, what were you trying to determine, and what topic in physics were you studying?

2) Your hypothesis and justification of your hypothesis.

   Example: I think that copper will sink when placed in water because its density is higher than water, so it will overcome the buoyancy force.

3) The equipment you used

4) The procedure you used to test your hypothesis listed step-by-step. This should also explain how you used the equipment to get your data.

5) Your data, which should be organized in a table.

6) An analysis of your data to confirm or disprove your hypothesis

   Example: From my measurements of diameter and height, I was able to determine the volume of the cylinder (using or analyzing your data to determine something). This calculation and the measurement of mass allowed me to determine its density. From this calculation, I concluded my sample was copper.

7) What were your sources of error in your experiment? How can you improve those errors to make your measurements more precise?

Free Fall: Picket Fence

Introduction:

An object is in *free fall* if the only force acting on it is gravity. The acceleration due to gravity, g, can be considered constant for objects moving close enough to the Earth's surface.

It is an interesting result that g is independent of the mass of the object. However, the value of g varies with the distance from Earth and depends on the mass of the Earth and the distance between the object and the center of the Earth. If you are on Earth's surface, then:

$$g = G\frac{M_E}{{R_E}^2}, \tag{1}$$

where M_E and R_E are the mass and radius of the Earth and G is and the universal gravitational constant. The experimentally determined value of the gravitational acceleration near the Earth's surface is g = 9.81 m/s^2. The value of g was first determined experimentally by Galileo, who measured the time it took for various objects to roll down an inclined plane.

Acceleration is defined as the rate at which an object changes its velocity. Any constant acceleration motion, including free fall, is expressed by a simple equation:

$$v_f = v_i + a\Delta t\ , \tag{2}$$

where v_i and v_f are the initial and the final velocities, and a is the constant acceleration, and Δt is the time elapsed from when the object had its initial velocity v_i up to when it obtains its final velocity, v_f: $\Delta t = t_f - t_i$. Equation (2) corresponds to a standard linear dependence (velocity *vs.* time) of the general form $y = mx+b$, where m is the slope and b is the y-intercept. In the specific case of Eq.(2), the initial velocity v_i is the y-intercept and the acceleration a is the slope. Eq.(2) can be rearranged to solve for acceleration:

$$a = \frac{v_f - v_i}{\Delta t}. \tag{3}$$

Imagine the motion of an object in free fall dropped straight down, say a stone dropped from a bridge. To be specific, imagine that you could take very fast exposure photos of the stone as it falls, at a specific frequency (say 100 photos every second, such that 1 photo is recorded every 0.01 second). What would the sequence of photos look like? Think carefully about what acceleration means. If an object falls with a constant acceleration of 10 m/s^2, this means that every second the speed *increases* by 10 m/s. After 1 second, the object is moving at 10 m/s. After 2 seconds, it is moving at 20 m/s – and so it has covered more distance between 1-2 seconds than it did between 0-1 seconds. Therefore, the sequence of photos will show an increase in the separation between successive frames.

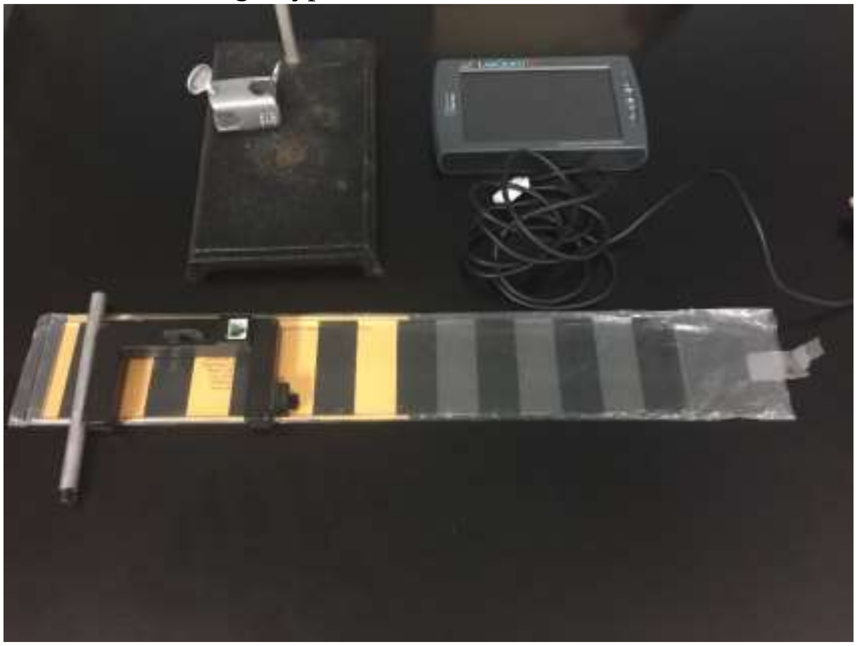
Since the acceleration is constant, the average and instantaneous accelerations are equivalent. The velocity however, is changing at a constant rate. We can calculate the instantaneous velocity v_n at some time t_n by instead computing the average velocity over a time interval where that time occurs in between the two endpoints:

$$v_n = \frac{\Delta x_{n+1,n-1}}{\Delta t_{n+1,n-1}} = \frac{x_{n+1} - x_{n-1}}{t_{n+1} - t_{n-1}}. \tag{4}$$

For example, the instantaneous velocity at time t_3 is $v_3 = \frac{\Delta x_{4,2}}{\Delta t_{4,2}}$, where $\Delta x_{4,2}$ is the distance between points 4 and 2.

Prompt:

The goals of this experiment are to visually understand the acceleration due to gravity near the Earth's surface g, and to experimentally measure the value of g. Hypothesize what this value should be.



You will have access to the following equipment:

1. Photogate.
2. Lab Quest 2
3. Picket Fence.
4. Soft surface for Picket Fence to land on (Backpacks are fine)

The photogate is integrated with the LabQuest system. The photogate is activated when something blocks it (like the black slats on the picket fence for instance). The LabQuest can use this data to map out the velocity of the picket fence as a function of time.

You will need to determine:

1) The velocity of the picket fence as a function of time
2) The acceleration due to gravity of the photogate.
3) The percent error of your experimental g.
4) Reasons for why your experimental g differs from the theory.

Some experimental help:

Fasten the Photogate rigidly to a ring stand so the arms extend horizontally, as shown in Figure 1. The entire length of the Picket Fence must be able to fall freely through the Photogate. To avoid damaging the Picket Fence, make sure it has a soft surface (such as a carpet) to land on.

Set up shown Below:

Connect the Photogate to the DIG 1 input of the LabQuest2.

The photogate will not automatically load in the Lab Quest2 and must be manually set up. In order to do this, select the sensor icon in the top left of the screen. You will see a blank menu. On this menu select "Sensors" located at the top of the Screen and select Sensor Setup.

Select the bar that reads "No Sensor" next to DIG 1. A list of sensors will appear. Select photogate from the list

Once the photogate is selected and you return to the sensor menu you will see a box that says unblocked in big letters.

Block the Photogate with your hand; note that the Photogate is shown as blocked. Remove your hand and the display should change to unblocked.

Make sure that the photogate is correctly calibrated for your picket fence in the sensors menu:

On the sensor menu click Mode, located on the right of the screen. It should read "time based"

On the bottom of this menu expand the option “Photogate Mode: Motion”

The sensor default setting should read “Vernier Picket Fence” which is what you are using.

Select the “graph” Button in the top right-hand corner of the LabQuest. After the graphs are on the screen press the green “play” button in the lower right-hand corner to activate the Photogate.

Hold the top of the Picket Fence and drop it through the Photogate, releasing it from your grasp completely before it enters the Photogate.

Be careful when releasing the Picket Fence. It must not touch the sides of the Photogate as it falls, and it needs to remain vertical. Click the stop button to end data collection. Note: When you push the play button it turns into the stop button.

Examine your graphs. The slope of a velocity *vs.* time graph is a measure of acceleration. If the velocity graph is approximately a straight line of constant slope, the acceleration is constant.

If the acceleration of your Picket Fence appears constant, fit a straight line to your data. To do this, click on the velocity graph once to select it, then click to fit the line
$y = mx + b$ to the data, which can be found under Analyze- Curve Fit- Linear. Record the slope in the data table.

To establish the reliability of your slope measurement, repeat this process five more times. Do not use drops in which the Picket Fence hits or misses the Photogate. Record the slope values in the data table.

Static and Kinetic Friction

Introduction:

Friction is the force resisting the relative motion of surfaces sliding against each other (or trying to move across each other). There are at least two types of friction - *kinetic* (sliding) and *static* friction.

When you attempt to push a heavy box resting on the floor, you need to apply a certain amount of force in order for the box to move. While the box is stationary, static friction is pushing against the external force applied; they are equal in magnitude and opposite in direction. The free-body diagram while you are pushing and the box is stationary is:

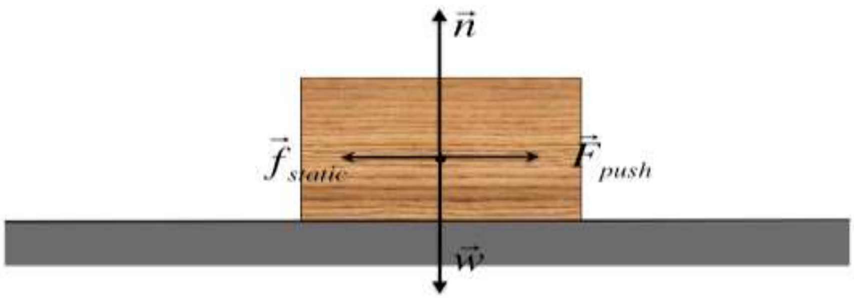


Figure 1

As you push harder, static friction increases and remains equal to the value of your pushing force. Eventually, if you push hard enough, the box will move; this means that static friction has reached its maximum magnitude. There are two factors which determine the maximum static frictional force which can occur between two surfaces: how "grippy" the surfaces are (friction coefficient), and how hard the two surfaces are being pushed together (normal force):

$$f_s \le f_{s,max}\,, \tag{1}$$

$$f_{s,max} = \mu_s n,$$

where μ_s is the coefficient of static friction and depends on the two surfaces that are in contact and n is the normal force. In this particular case where the object is moved on a horizontal surface, the normal force is equal to the weight:

$$n = mg. \tag{2}$$

Once the box moves, it will be opposed by kinetic friction. The equation for kinetic friction looks very similar to that for static friction (1):

$$f_k = \mu_k n. \tag{3}$$

Now the coefficient of friction is μ_k, which lower than μ_s for the same two surfaces. This makes sense: it is easier to keep the box moving once you have overcome static friction.

Prompt:

The goals of this lab are to:
(1) measure and compare static and kinetic friction forces
(2) measure the coefficients of friction of the wooden block.
(3) determine the relationship between the *normal* and frictional forces.

You will have access to the following equipment:

1. Dual-Range Force Sensor
2. Wooden block
3. Masses
4. String

The Dual-Range Force Sensor measures the force exerted on its hook as a function of time. You can use this to measure the force of friction (think about why).

Help with setting up the force sensor:

a. Connect the Force Sensor to digital Channel 1 of the LabQuest data-collection device.

b. Set LabQuest device to "Force Sensor" in digital Channel 1 and set the range to 50 N. The graph on the screen will show force versus time.

c. Tie one end of a string to the hook on the Force Sensor and the other end to the hook on the block. Place some masses on top of the cart. Practice pulling the block and masses horizontally with the Force Sensor along a straight line. Gradually, increase the force until the block starts to slide, and then keep the block moving at a constant speed.

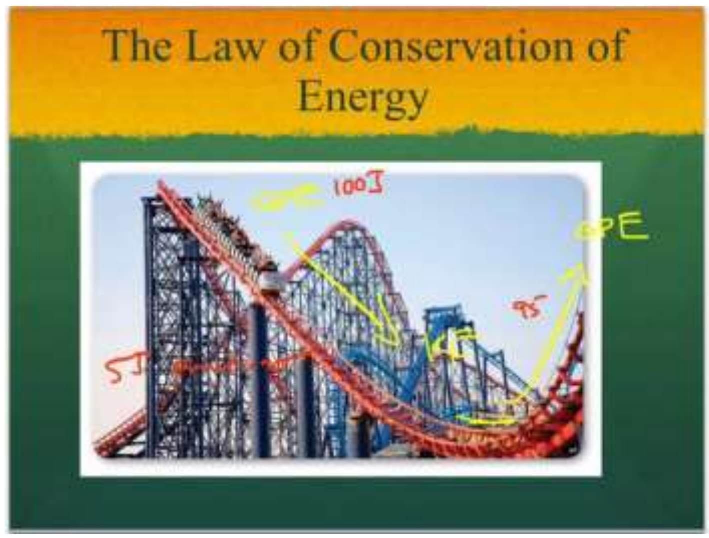
d. Practice until your force-time graph shows two distinct regions: one part with a positive slope (static friction regime) and the other with nearly zero slope (kinetic friction regime).

Conservation of Energy

In an isolated system, the total energy is conserved. External forces that act on the system can change its total energy. In certain cases, the change in the total energy depends upon the path the object takes while the external force is applied. This is an example of a *non-conservative force.*

Introduction

The conservation of energy is a very powerful statement. It tells us that if we know the total energy of a system at *any* instant in time, then we also know the total energy of the system at *all points in time*.



In mathematical form, we can write the conservation of energy as:

$$\Delta K + \Delta U = W + W_{nc} \qquad (1)$$

If the system is isolated, then there is *no total change in both the kinetic AND potential energy* of the system. Instead, energy can only be transferred BETWEEN kinetic and potential energy (like the roller coaster pictured above).

If the system is non-isolated, then external forces act on it. We say that these external forces can do *work.* The work done by a constant force is defined as:

$$W = F\Delta r \cos\theta \qquad (2)$$

Where theta is the angle between the external force and the displacement of the object. If the force is *conservative*, then the work done only depends upon the starting point and the ending point, rather than the path itself. Gravitation is one example- the work done by (or against) the gravitational force only depends upon the vertical displacement, i.e. the change in height.

Friction is an example of a *non-conservative force.* The amount of work it does depends on the path the object take as friction opposes it. Since the force of kinetic friction is always opposite the motion and perpendicular to the surface, we can write that the work done by friction is:

$$W_{nc} = -f_k \Delta r \qquad (3)$$

Note: other types of forces can be non-conservative too.

In the experiment, we will place the cart on a level, horizontal track and push the cart along the track. There will be no changes in its potential energy. After the initial push, no external forces will act. Therefore, the conservation of energy dictates that:

$$K_i = K_f + f_k \Delta r \qquad (4)$$

Prompt:

The goal of this experiment is to determine the work done by the frictional force when a cart travels along a horizontal track as a function of the distance it travels. You should come up with a testable hypothesis related to this topic.

Over the course of the experiment, you will need to measure:

1) The initial kinetic energy (immediately after it is pushed)
2) The final kinetic energy (you'll need to determine what this means in context)
3) The displacement of the cart
4) The force of kinetic friction
5) The experimental coefficient of kinetic friction.

You will have access to the following equipment:

1. LabQuest 2
2. Motion Detector
3. Track
4. Cart

The motion detector works with the LabQuest system. It tells you how far away the object is from the motion detector as a function of time.

Conservation of Momentum

Introduction:

The *law of conservation of momentum* states that if there are no external forces acting on a system, the total momentum of that system must conserved in both magnitude and direction. Let's consider a set of particles (for example, stars) interacting with some internal and external forces. We can state:

- there could be billions of them - a whole star cluster, the particles could collide with each other, explode, break apart – all of those forces are internal; they do not count. The momentum of the whole system would not change if the net external force is zero, $\vec{F}_{ext} = 0$.
- the individual particles will change their momentum all the time because they experience a non-zero net force. We are not saying that the individual particles do not experience the momentum change, only total momentum is conserved.

Figure 1. NGC206 - Star Cloud in Andromeda Galaxy

If we use the symbols $\sum p_i$ and $\sum p_f$ to denote the total initial and final momentum, respectively, along a particular direction (e.g. the x axis), the momentum conservation law can be expressed as:

$$\sum_i p_i = \sum_f p_f. \tag{1}$$

If our system of interest consists of only two objects, the above equation can be explicitly expressed as (since p=mv):

$$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}, \tag{2}$$

where m_1 and m_2 are the masses of the carts, respectively, and $v_{\alpha i(f)}$ is the velocity of the α^{th} cart just before (just after) the collision**. Note: this is a vector equation**. *You must account for magnitude and direction.*

In the case of an elastic collision, the total kinetic energy is also conserved, and we therefore have the following relation:

$$\frac{m_1 {v_{1i}}^2}{2} + \frac{m_2 v_{2i}^2}{2} = \frac{m_1 {v_{1f}}^2}{2} + \frac{m_2 v_{2f}^2}{2}. \tag{3}$$

Note, however, that in the case of an inelastic collision, the total momentum is conserved but total kinetic energy is certainly not since some (or possibly all) initial kinetic energy is dissipated into heat.

Prompt:

You should consider three types of collisions: elastic, inelastic and perfectly inelastic. You will observe each collision and hypothesize whether it is elastic or inelastic. You will use the theory outlined above to prove if the collisions are elastic or inelastic. Additionally, you will calculate energy losses throughout the experiment to test common assumptions made in problem solving exercises.

You will have access to the following equipment:

1. LabQuest 2
2. Motion Detectors
3. Track
4. Cart with Magnet / Cart With Velcro

The motion detector works with the LabQuest system. It tells you how far away the object is from the motion detector as a function of time.

You will need to measure:

1) The total momentum of the system before and after each type of collision
2) The total kinetic energy of the system before and after each type of collision
3) Whether the total momentum is conserved or not and why.
4) Whether the total kinetic energy is conserved or not and why.
5) Whether the collision is elastic or inelastic.

Torque and Static Equilibrium

Introduction:

A solid object is in static equilibrium, if the following conditions are satisfied:

$$\vec{F}_{Net} = \sum_{i=1}^{N} \vec{F}_i = 0, \tag{1}$$

$$\vec{\tau}_{Net} = \sum_{i=1}^{N} \vec{\tau}_i = 0. \tag{2}$$

Equations (1) and (2) are really sets of three independent equations each in terms of their *x*, *y*, and *z* component directions. The net force (1) expresses the net tendency for a system to move as a whole body (usually we speak about the motion of the center of mass) and the net torque (2) describes the net tendency for a system to spin about a point (an arbitrary reference point, usually the pivot point; so long as the system is balanced, both the net force and the net torque are zero.

Figure 1 shows a system, consisting of a rigid rod upon which three masses are balanced:

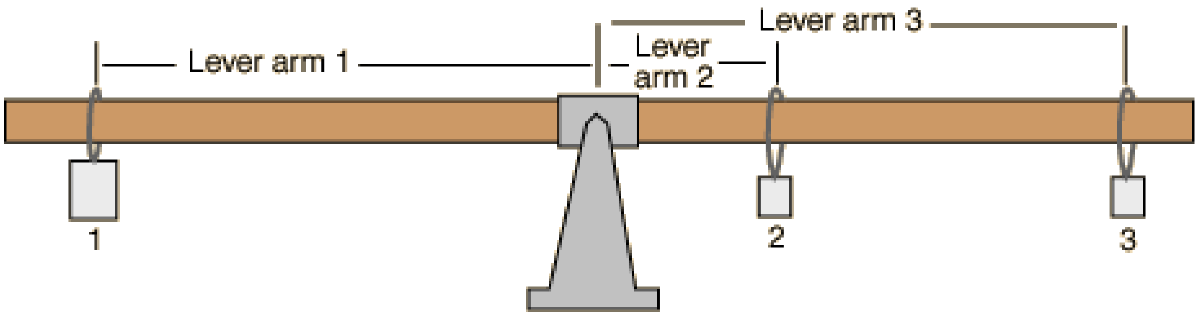


Figure 1

Each hanging weight contributes a torque about the pivot point (i.e., the fulcrum). Since the weights are perpendicular to their lever arms, the magnitude of the torque produced by any individual weight can be calculated as:

$$\tau = mgl, \tag{3}$$

where l is the lever arm, which is the distance from the pivot point to the respective weight.

In the case shown above, we have:

$$\tau_1 = m_1 g l_1, \quad (4)$$

$$\tau_2 = m_2 g l_2, \quad (5)$$

$$\tau_2 = m_2 g l_2. \quad (6)$$

It should be noted that torque is a vector $(\vec{\tau} = \vec{r} \times \vec{F})$, and as such, the direction of the torque must be accounted for; for example, a clockwise rotation yields a negative torque value.

Prompt:

The goal of this experiment is to analyze cases in which the net torque, as well as the net force, acting on a system of interest equals zero- in this case a meter stick from which you hang masses supported by holders. You will have access to the following equipment:

1. Meter stick
2. Meter stick clamps (knife edge)
3. Weights
4. Fulcrum (balance support)

For three different configurations where you hang different masses on the meter stick, determine:

1) The center of mass of the ruler (think about why this might be useful)
2) When the system is in equilibrium (how can you tell?)
3) The positions of each of the masses when the system is in equilibrium (relative to what)?
4) The experimental torque for each set-up.