Lab 2: Newton's Laws of Motion (M2)

Isaac Newton formulated laws to explain the relationship between force and motion. In this lab, you will explore Newton's three laws of motion by studying velocity vs. time, acceleration vs. time and force vs. time graphs.

Objectives

- Understand Newton's three laws of motion.
- Examine motion by creating acceleration vs. time graphs.
- Learn about the relationship among acceleration, velocity and position as they vary with time.
- Discover how force relates to motion.

Newton's Laws

• **First Law**: A body at rest remains at rest, and a body in motion continues to move at constant velocity unless acted upon by an external force. The tendency of an object either to remain at rest or to maintain a state of uniform motion in a straight line is called *inertia*.

• **Second Law**: External force acting on a body gives it an acceleration that is in the direction of the force and has a magnitude directly proportional to the magnitude of the force and inversely proportional to the mass of the body.

$$\boldsymbol{a} = \boldsymbol{F}/m \quad \text{or} \quad \boldsymbol{F} = m\,\boldsymbol{a}$$

The direction of the acceleration is in the direction of the resultant force.

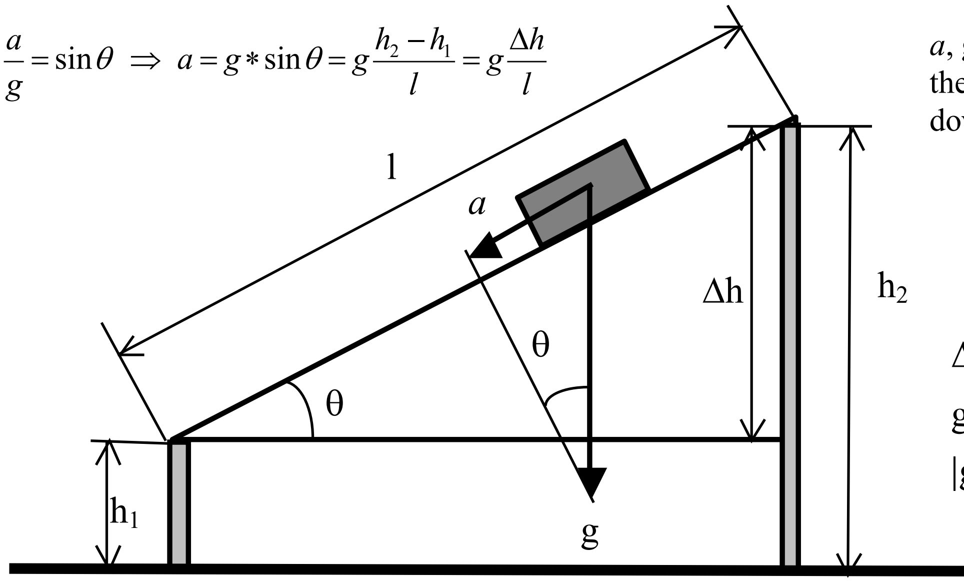
• **Third Law**: Whenever a body exerts a force on another body, the latter exerts a force of equal magnitude and opposite direction on the former. For every *action,* there is an equal and opposite *reaction*.

Acceleration on an incline

The gravitational acceleration of a block down an incline is given by the following formula (ignoring friction):

$$\frac{a}{g} = \sin\theta \Rightarrow a = g * \sin\theta = g\frac{h_2 - h_1}{l} = g\frac{\Delta h}{l}$$

a, g < 0, because they are pointing down.



$\Delta h = h_2 - h_1$

$g = -9.80\ m/s^2$

$|g| = 9.80\ m/s^2$

Figure 1. A block accelerating on an incline.

Acceleration of two masses

The acceleration value *a* for two masses connected by a thin string (mass of the string is negligible) is given by the following formula (ignoring friction):

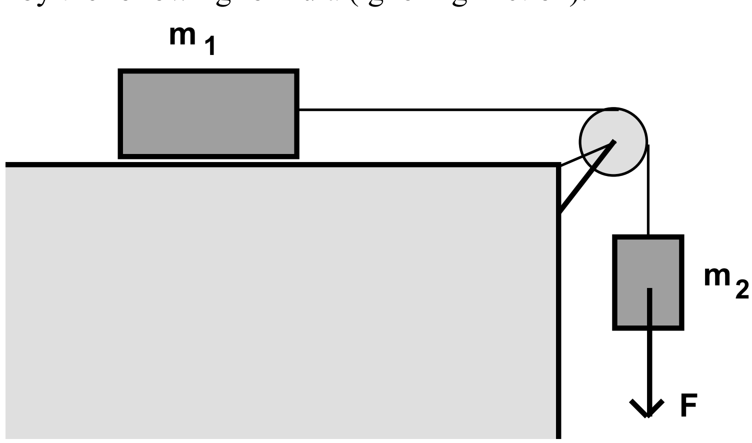


Figure 2. Acceleration of two masses.

$$F = m_2 g = a(m_1 + m_2) \quad \Rightarrow \quad a = \frac{m_2 g}{(m_1 + m_2)}$$

If $m_2 >> m_1$, then $m_1 + m_2 \cong m_2$ and $a = \frac{m_2 g}{(m_1 + m_2)} \cong \frac{m_2 g}{m_2} = g$; If $m_1 = 0$, then $a = g$.

If $m_2 = m_1$, then $a = g/2 = 0.5*g$

If $m_2 << m_1$, then $m_1 + m_2 \cong m_1$ and $a = \frac{m_2 g}{(m_1 + m_2)} \cong \frac{m_2}{m_1} * g$; If $m_2 = 0$, then $a = 0$.

Kinetic friction force

When an object slides along another object, both touching surfaces the exert the kinetic friction force on each other. The kinetic friction force is proportional to the kinetic friction coefficient μ_k and to the normal force N exerted by the two objects on each other. The kinetic friction coefficient μ_k characterizes the surfaces – both the type of material and the quality of the surface (smooth or rough).

$$F_{FRICTION} = \mu_k N$$

For an object located on a horizontal surface (just like mass m_1 on Figure 2) the normal force is simple equal to the weight of the object. Therefore,

$$F_{FRICTION} = \mu_k N = \mu_k m_1 g$$

Consider the situation illustrated in Figure 2. If there is a significant kinetic friction between mass m_1 and the horizontal surface, then we would also have to include the friction force in the calculation of the net force F.

$$F = m_2 g = a(m_1 + m_2) + F_{FRICTION} = a(m_1 + m_2) + \mu_k m_1 g$$

Set-up:

A hanging mass will be used to illustrate Newton's second law. Because the acceleration due to gravity g is constant and equal to 9.80 m/s^2 , the weight of the mass is a constant force ($F = mg$ or along the incline $F = mg\sin\theta = mgh/l$).

Force probes will be used to measure quantitatively the amount of push or pull experienced. Proper equipment adjustment is essential for successful measuring. Before beginning the exercises, calibrate the equipment using a value that you know. For force probes, it is convenient to calibrate to zero.

Procedure:

You will be required to login using your Purdue career account. Enter your login name and password. *Download the Capstone files for experiment M2 using the same method as for previous labs and save them to desktop.*

Activity 1: Constant Acceleration

Double-click on the "M2 Activity 1" icon. Place the collision cart (both carts are labeled) on the track so that <u>its sail is closer to the wall</u> - as shown on the picture below. Begin recording by clicking on the 

button. There should be <u>no motion of the cart</u>. Since the collision cart is not moving, the computer-generated graph should show that both velocity and acceleration of the cart are zero and the position of the cart is constant. This is a test of your setup. If your equipment is not working properly, <u>notify your Teaching Assistant immediately</u>. If no external force is introduced, your cart will remain in this position (at rest) forever in accordance with Newton's First Law.

Insert the aluminum block under the legs away from the wall to create an <u>incline</u>.

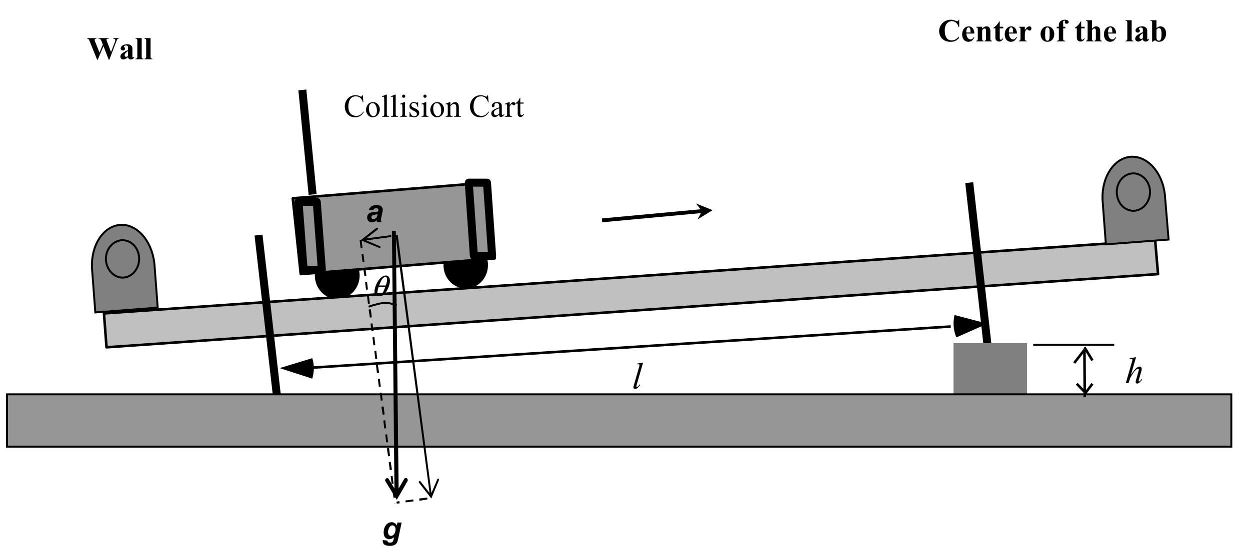


Figure 3. The inclined track supported by the aluminum block.

Briefly, <u>push</u> the cart up the incline and let it go. The cart will move up the track and later will return to its starting position. Make sure that the cart does not hits the bumper at the top of its path.

Examine the acceleration, velocity, and position graphs produced paying particular attention to the acceleration graph. Does the **shape** of the acceleration vs. time graph match the one that you predicted in Prelab Question 1? Remember, that **the acceleration is going to be negative** because the gravity component along the track is pointing towards the motion sensor.

Select a section of the graph with approximately constant acceleration and use the  button to read **five consecutive values of the acceleration**. Record these values on your data sheets. Calculate the average acceleration and the standard deviation of acceleration (*as you did for experiment M1*). Measure and record the distance between the two outside legs supporting the track on your data sheet (labeled 'l' in Figure 3). Calculate the theoretical value of the acceleration (use Δh = 5.08 cm = 2"). Calculate the absolute and percent differences between experimental (average) and theoretical values of acceleration.
Exit *Capstone* without saving any changes.

Activity 2: Newton's Second Law

Newton's Second Law describes the relationship between the motion of an object and the magnitude of the force acting upon it.

Select: "M2 Activity 2" and open it.

Remove the block from beneath the incline, returning the track to its initial **horizontal position**. Measure the mass M of the cart using the scale available in the lab and record it on your data sheets.

Attach one end of the **long string (cart string)** to the side of the cart that is opposite to the sail by looping the string through the small hole at the top of the black bumper. Allow the string to flow across the pulley at the end of the track and attach the other end of the string to the mass hanger as shown below in Figure 4.

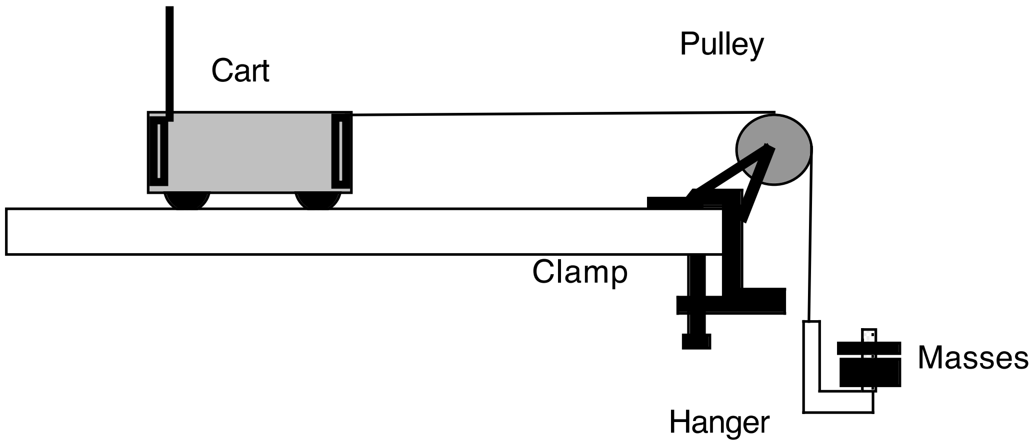


Figure 4. Cart with the pulley and hanging masses.

While holding the cart steady, place the 20g and 5g circular masses onto the mass hanger. There should be no slack in the string. Move the cart to the midway position on the track. The cart should be ready to move when you release it. The gravitational force will act on the hanging mass and (because the string connects the cart with the falling mass) moves the cart.

Calculate the hanging object's weight and write it on the data sheets. The <u>hanger has a mass of ~5 grams</u>. The combined mass of the plastic hanger and the two brass circular masses is now 30 g. Remember, that weight is a force and is measured in Newtons ($1\ kg*m/s^2 = 1\ N$).

Start recording data. <u>After</u> hearing the noise created by the motion sensor, **release the cart** and watch the mass falling towards the floor. Be sure that the string does not interfere with the bumper and that the hanging object stops just above the floor. **Print** this graph.

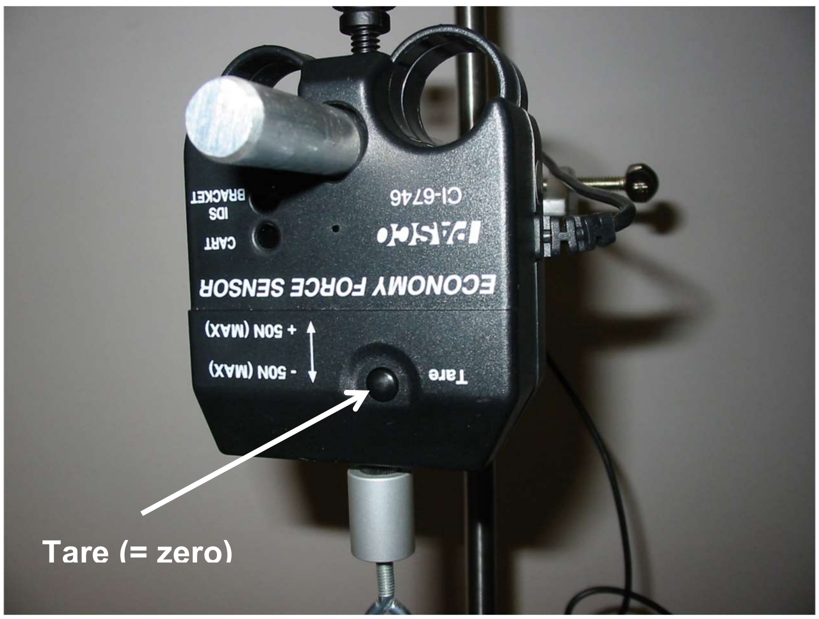
Ignore data recorded after the cart hits the bumper but pay attention to the acceleration graph as it varies with time. Use the "Smart Tool"  icon to read five consecutive acceleration values from the graph during the time when the cart is undergoing constant acceleration due to the hanging mass. Record these values of the cart's acceleration on your <u>data sheet</u>.

Calculate the average acceleration and the standard deviation of acceleration. Calculate the theoretical value of the acceleration using the formula provided at the beginning of this description file. Does the theoretical value agree with the measured average acceleration (within experimental error)? If not, try to explain why. Calculate the absolute and percent differences between experimental (average) and theoretical values of acceleration.

Activity 3: Force Probe as Electronic Balance

For the remaining two activities, we will be using the PASCO force sensors called "Economy Force Sensor". To set up for these activities, select **Open Activity** from the **File** menu. A window asking whether you wish to save changes will appear. Don't save any changes. Select: "M2 Activities 3-4 "and open it.

Because you are using different equipment, you will need to check to make sure that the two force sensors are calibrated correctly. Hold the two force sensors without attaching anything to the hooks. Press the "Tare" button on both sensors to zero force sensors.



Using the computer, collect data. Examine the force graphs. The measured force should be zero (because there are no external forces acting on the sensors). If the results differ significantly from zero, then press the "Tare" button again. However, remember that the signal from the force sensors includes some electrical noise. As long as the noise is scattered both above and below zero, the equipment is working properly, and the sensors do not need to be adjusted.

The force sensors have been labeled A and B. Put the sensor "B" on the short aluminum rod clamped to the lab table. Make sure that the sensor is hanging vertically. Attach a loop of the string marked "force probe" to the hook of sensor "B". Next, attach the mass hanger and 200 grams to the other loop. Make sure that the string hangs vertically downward and that the mass is not touching you or the table. (See Figure 5 below)

On your data sheet, write down the measured force from the graph. Calculate the relative error (percentage) between the calculated and measured forces.

Figure 5

Force graphs for both sensors A and B are generated out of which in this activity you are concerned with only B. If you have more than one set of data runs, then the computer will automatically display only the most recent set. Select the run that you want to view from the "Data" pull-down menu.

Activity 4: Newton's Third Law

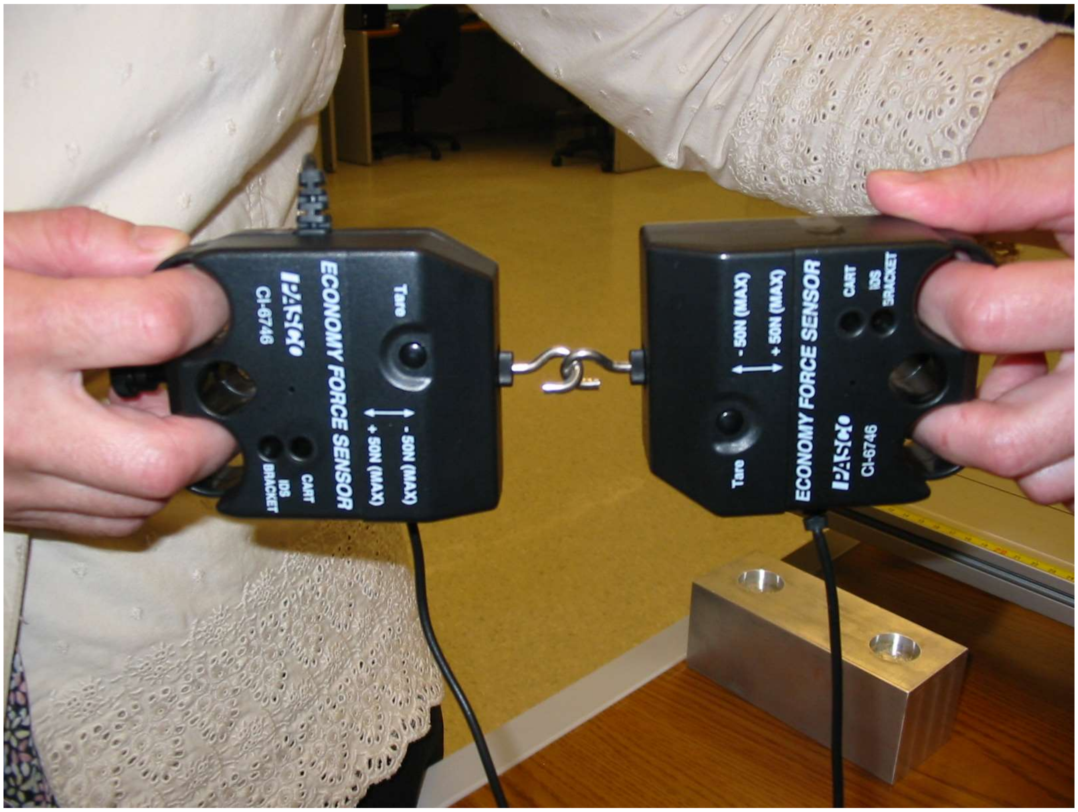


Figure 6.

A. Hold both force sensors horizontally. Connect the hooks of the two force sensors together (as shown in Figure 6). Pull on the two sensors in opposite directions for a variety of force values, but **do not use excessive force** (i.e., exceeding 10 N). Collect data.

Keep the force sensors hooked together. Try to pull only one sensor, but do not pull the other one. Can you get a zero-force recorded by one sensor and significantly non-zero force measured by the other sensor? Can you really pull only one sensor without pulling the other? What physics law describes this situation?

B. Attach sensor B to the lab bench using the clamp. Hook sensor A to sensor B as shown in Figure 7 below. By pulling only on sensor A, apply a similar force to sensor A as when you held sensor B in your hand. Are the measured forces still approximately equal and opposite? Does Newton's Third Law apply in this case?

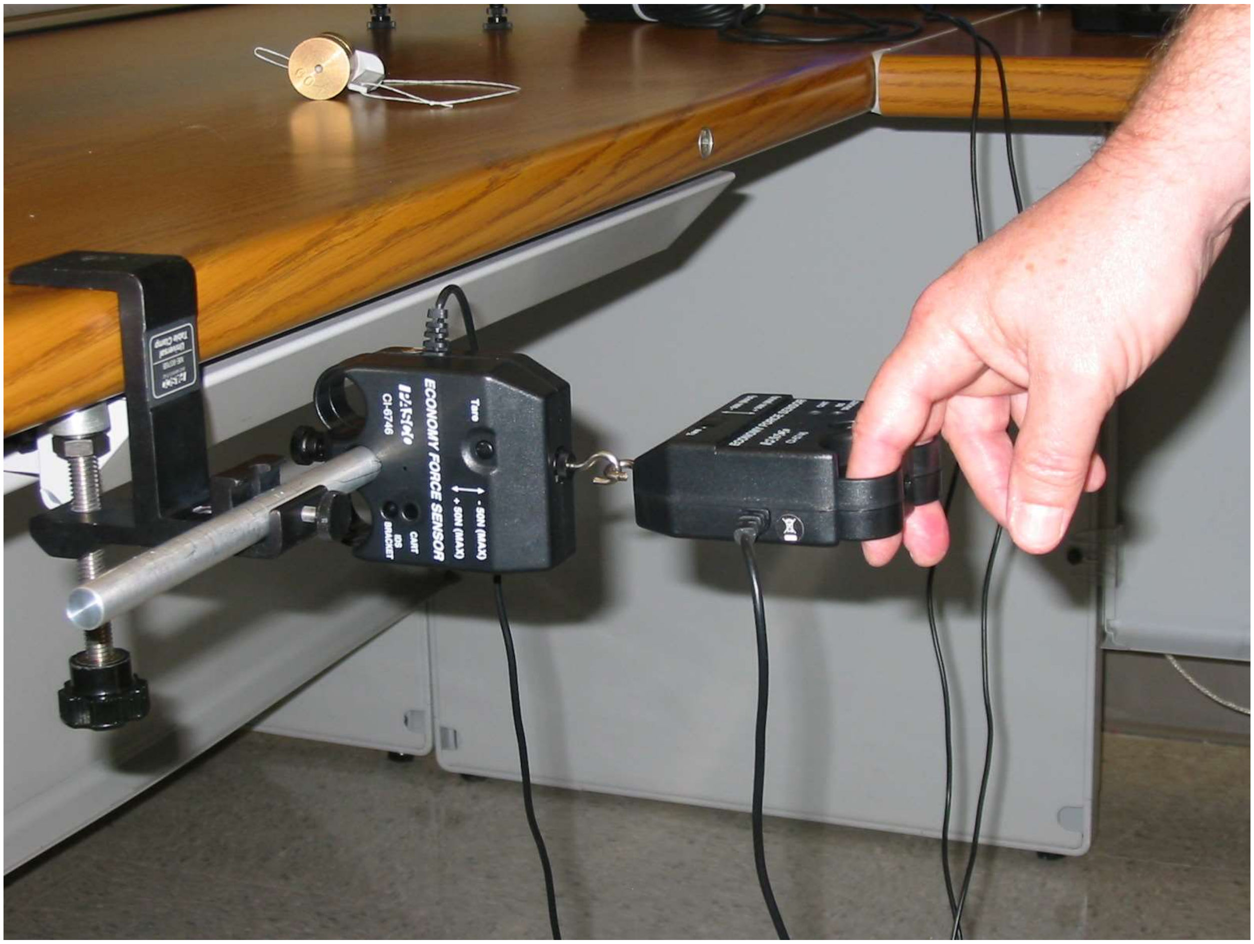


Figure 7.

Students are expected to **complete the lab report and return it to the lab TA** before the end of the scheduled lab time.

Make sure to complete the following tasks while in the lab room:

You must submit the answers to the prelaboratory questions online. (3.5 points)

1. Three graphs printed during *Activities* 1, 2, and 4.
   (Write the title as well as student names and on each graph.) (3×1 point = 3 points)
2. Your completed Data Sheets. (3.5 points)
3. **Return** completed lab report to your lab TA.