

**GENERAL PHYSICS  
PART A: MECHANICS  
EXPERIMENT-1  
VECTOR ADDITION**

**1. PURPOSE**

The purpose of this experiment is to use the force table to experimentally determine the force which balances two other forces. This result is checked by adding the two forces using their components and by graphically adding the forces.

**2. THEORY**

Many physical quantities can be completely specified by their magnitude alone. Such quantities are called scalars. Examples include such diverse things as distance, time, speed, mass and temperature. Another physically important class of quantities is that of vectors, which have direction as well as magnitude.

**A-) Experimental Method:** Two forces are applied on the force table by using masses over pulleys positioned at certain angles. Then the angle and mass hung over a third pulley are adjusted until it balances the other two forces. This third force is called the equilibrant ( $\vec{F}_E$ ) since it is the force which established equilibrium. The equilibrant is not the same as the resultant ( $\vec{F}_R$ ). The resultant is the addition of the two forces. While the equilibrant is equal in magnitude to the resultant, it is in the opposite direction because it balances the resultant (see Fig.1.1). So the equilibrant is the negative of the resultant:

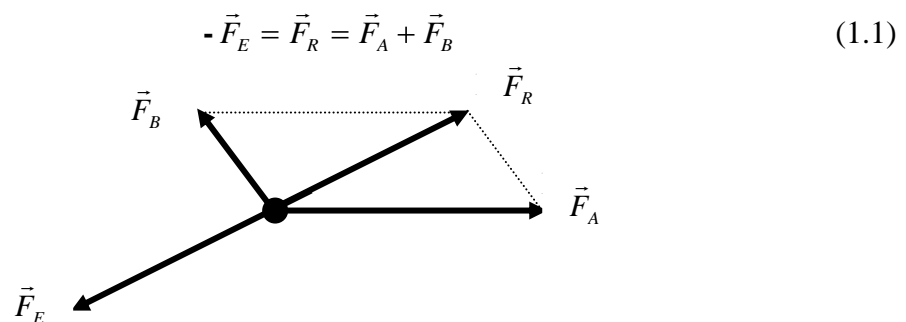


Figure 1.1: The equilibrant balances the resultant

**B-) Component Method:** Two forces are added together by adding the x- and y-components of the forces. First the two forces are broken into their x- and y-components using trigonometry:

$$\vec{F}_A = A_x \hat{x} + A_y \hat{y} \quad \text{and} \quad \vec{F}_B = B_x \hat{x} + B_y \hat{y} \quad (1.2)$$

where  $A_x$  is the component of the vector  $\vec{F}_A$  and  $\hat{x}$  is the unit vector in the x-direction as shown Fig. 1.2. To determine the sum of  $\vec{F}_A$  and  $\vec{F}_B$ , the components are added to get the components of the resultant  $\vec{F}_R$ .

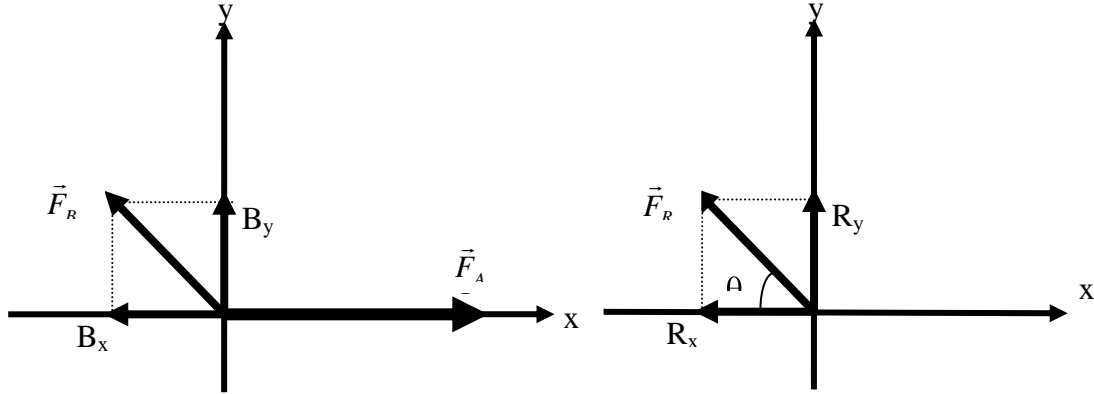


Figure 1.2: Vector Components

$$\vec{F}_R = (A_x + B_x)\hat{x} + (A_y + B_y)\hat{y} = R_x\hat{x} + R_y\hat{y} \quad (1.3)$$

To complete the analysis, the resultant force must be in the form of a magnitude and a direction (angle). So the components of the resultant ( $R_x$  and  $R_y$ ) must be combined using the Pythagorean theorem since the components are at right angles to each other:

$$|F_R| = \sqrt{R_x^2 + R_y^2} \quad (1.4)$$

and using trigonometry gives the angle:

$$\tan \theta = \frac{R_y}{R_x} \quad (1.5)$$

**C-) Graphical Method:** Two forces are added together by drawing them to scale using a ruler and protractor. The second ( $\vec{F}_B$ ) is drawn with its tail to the head of the first force ( $\vec{F}_A$ ). The resultant ( $\vec{F}_R$ ) is drawn from the tail of the  $\vec{F}_A$  to the head of  $\vec{F}_B$  as shown in Fig.1.3. Then the magnitude of the resultant can be measured directly from the diagram and converted to the proper force using the chosen scale. The angle can also be measured using the protractor.

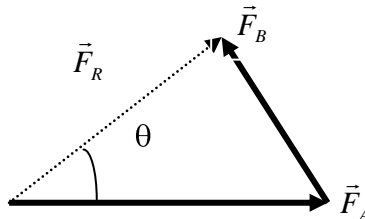


Figure 1.3: Adding vectors head to tail

### 3. EXPERIMENTAL PROCEDURE

1. Assemble the force table as shown in the Assemble section. Use three pulleys (two for the forces that will be added and one for the force that balances the sum of the two forces).
2. If you are using the Ring Method, screw the center post up so that it will hold the ring in place when the masses are suspended from the two pulleys. If you are using the Anchor String Method, leave the center post so that it is flush with the top surface of the force table. Make sure the anchor string is tied to one of the legs of the force table so the anchor string will hold the strings that are attached to the masses that will be suspended from the two pulleys.
3. Hang the following masses on two masses on two of the pulleys and clamp the pulleys at the given angles:

$$\text{Force } \vec{A} = 500 \text{ N at } 0^\circ \quad (1.6)$$

$$\text{Force } \vec{B} = 1000 \text{ N at } 120^\circ \quad (1.7)$$

#### Experimental Method:

By trial and error, find the angle for the third pulley and the mass which must be suspended from it that will balance the forces exerted on the strings by the other two masses. The third force is called the equilibrant  $\vec{F}_E$  since it is the force which establishes equilibrium. The equilibrant is the negative of the resultant:

$$- \vec{F}_E = \vec{F}_R = \vec{F}_A + \vec{F}_B \quad (1.8)$$

Record the mass and angle required for the third pulley to put the system into equilibrium in Table 1.1. (page.16)

#### Ring Method of Finding Equilibrium:

1. The ring should be centered over the post when the system is in equilibrium. Screw the center post down so that it is flush with the top surface of the force table and no longer able to hold the ring in position. Pull the ring slightly to one side and let it go. Check to see that the ring returns to the center. If not, adjust the mass and/or angle of the pulley until the ring always returns to the center when pulled slightly to one side.
2. See Fig.1.4 to use this method, screw the center post up until it stops so that it sticks up above the table. Place the ring over the post and tie one 30 cm long string to the ring for each pulley. The strings must be long enough to reach over the pulleys. Place each string over a pulley and tie a mass hanger to it.

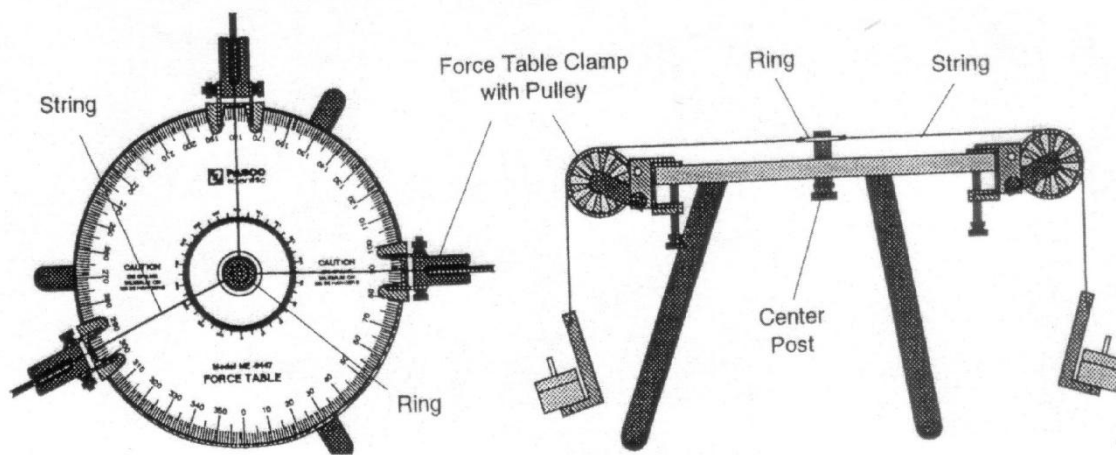


Figure 1.4: Ring method of stringing force table.

**Anchor String Method of Finding Equilibrium:**

1. The knot should be centered over the hole in the middle of the center post when the system is in equilibrium. The anchor string should be slack. Adjust the pulleys downward until the strings are close to the top surface of the force table. Pull the knot slightly to one side and let it go. Check to see that the knot returns to the center. If not, adjust the mass and/or angle of the third pulley until the knot always returns to the center when pulled slightly to one side.
2. See figure 1.5, cut two 60 cm lengths of string and tie them together at their centers. Three of the ends will reach from the center of the table over a pulley; the fourth will be threaded down through the hole in the center post to act as the anchor string. Screw the center post down so it is flush with the top surface of the table. Thread the anchor string down through the hole in the center post and tie that end to one of the legs. Put each of the other strings over a pulley and tie a mass hanger on the end of each string.

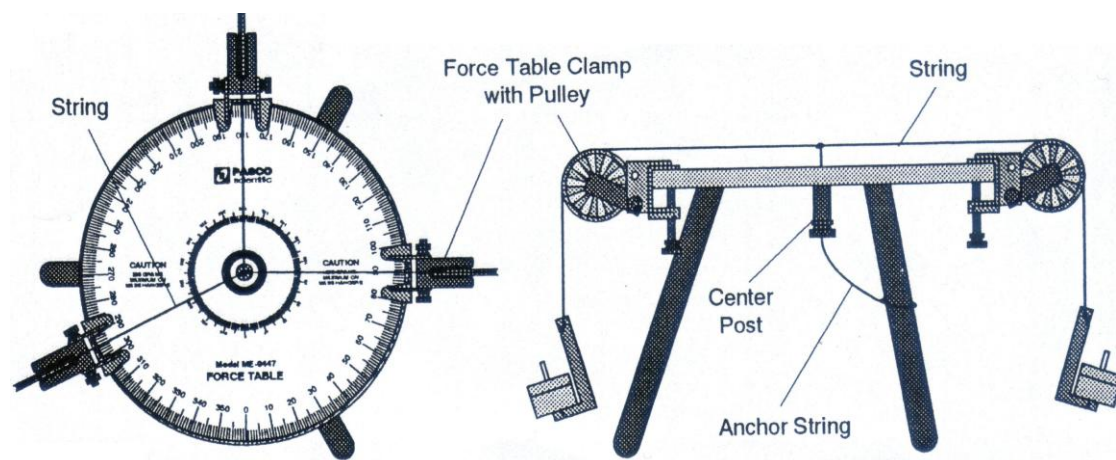


Figure 1.5: Anchor method of stringing force table.

#### 4. DISCUSSIONS AND CONCLUSIONS

1. To determine theoretically what mass should be suspended from the third pulley, and at what angle, calculate the magnitude and direction of the equilibrant ( $\vec{F}_E$ ) by the component method and the graphical method.

##### **Component Method:**

On a separate piece of paper, add the vector components of Force  $\vec{A}$  and Force  $\vec{B}$  to determine the magnitude of the equilibrant. Use trigonometry to find the direction (remember, the equilibrant is exactly opposite in direction to the resultant). Record the results in Table 1.1.

##### **Graphical Method:**

On a separate piece of paper, construct a tail-to-head diagram of the vectors of Force  $\vec{A}$  and Force  $\vec{B}$ . Use a metric rule and protractor to measure the magnitude and direction of the resultant. Record the results in Table 1.1. Remember to record the direction of the equilibrant, which is opposite in direction to the resultant.

2. How do the theoretical values for the magnitude and direction of the equilibrant compare to the actual magnitude and direction?
3. Three forces and their resultant and equilibrant. Draw the space diagram as before. Then solve (on a second sheet of graph paper) by the vector polygon method for the resultant and the equilibrant (The vector polygon method is merely an extension of the vector triangle plot. The last plotted vector should, except for experimental error, close the polygon). Finally, solve for the resultant (magnitude and direction) of the three forces by the analytically method, using the technique of resolving forces into their horizontal and vertical components.
4. Compare the results with the actual experimental values from the force table.
5. Explain how the experiment has illustrated the principles of vector addition. What does the vector equation  $\vec{R} = \vec{F}_1 + \vec{F}_2$  Express? How would you write the same expression in algebraic terms?

#### 5. QUESTIONS

1. List as many vector quantities as you can think of.
2. Show how you would add the following three vectors: 10 units North, 10 units South, and 10 units straight up.

3. Start by choosing a coordinate system and sketching the vectors. Use graphical techniques to get a qualitative estimate of the resultant.
4. Does a unit vector have units?
5. Add the x components algebraically to find the resultant a value and add the y component algebraically to find the resultant y value.
6. (a) If you walk three city blocks east and then four blocks north, how many blocks are you from your starting place? (b) What direction are you from the starting point? Give your answer as an angle measured from due east.
7. Add the following vectors graphically in the order given, then add them in reverse order on a separate diagram, thereby testing that vector addition is commutative: A = 5 units at  $60^\circ$  and B = 7 units at  $180^\circ$ .

**Table.1.1 : Data table**

<b>Table 1.1</b>		
Method	Equilibrant ( $F_E$ )	
	Magnitude	Direction ( $\theta$ )
Experiment:		
Component: $R_x =$ _____  $R_y =$ _____		
Graphical:		



**GENERAL PHYSICS  
PART A: MECHANICS  
EXPERIMENT – 2**

**ADDING FORCES-RESULTANTS AND EQUILIBRANTS AND RESOLVING  
FORCES-COMPONENTS**

**1. PURPOSE**

To study the adding forces and the resolving forces using components and equilibrants of the forces.

**2. THEORY**

A system of forces whose lines of action all pass through the same point is said to be a concurrent force system. Such a system of forces may be replaced by a single force through the same point, which would have the same effect or result as the force system. This single force is called the resultant of the system.

Conversely, a concurrent force system can be exactly balanced by single force. Such a balancing force is called the equilibrant. Its line of action is also through the point of concurrence. The resultant and the equilibrant of any concurrent system of forces are equal in magnitude and have the same line of action, but they are oppositely directed.

It is often to think of a vector as the sum of two or three other vectors. We call these other vectors components. Usually we choose components at right angles to each other. Resolving vectors into their components makes it easier to carry out mathematical manipulations such as addition and subtraction.

In two dimensions, we frequently choose the component vectors to lie along the x and y-axes of a rectangular coordinate system. For example, consider the vector  $\vec{A}$  lying in the x-y plane (Fig. 2.1). We can construct two component vectors drawing lines from the end of  $\vec{A}$  perpendicular to the x and y-axes. The two vectors that lie along the x and y-direction add to form  $\vec{A}$ . When we find the magnitude of these two vectors, we say that we have resolved the vector  $\vec{A}$  into its x and y component.



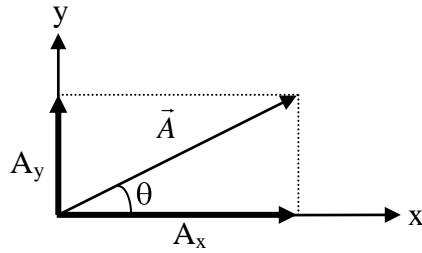


Figure 2.1: A vector  $\vec{A}$  lying in the x-y plane and components.

In Fig. 2.2, spaceships x and y are pulling on an asteroid with forces indicated by vectors  $\vec{F}_x$  and  $\vec{F}_y$ . Since these forces are acting on the same point of the asteroid, they are called concurrent forces. As with any vector quantity, each force is defined both by its direction, the direction of the arrow, and by its magnitude, which is proportional to the length of the arrow. (The magnitude of the force is independent of the length of the tow rop).

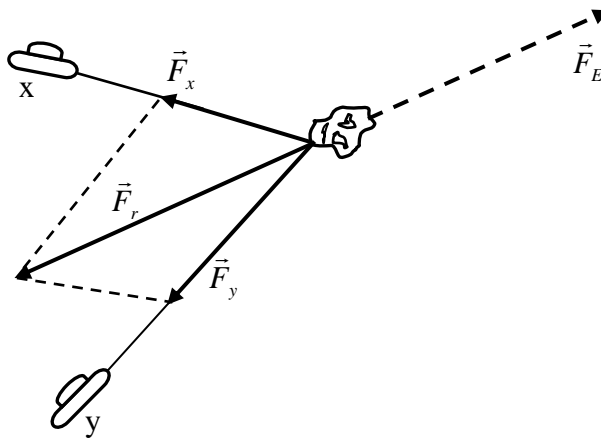


Figure 2.2: Finding the equilibrant of the concurrent forces.

The total force on the asteroid can be determined by adding vectors  $\vec{F}_x$  and  $\vec{F}_y$ . In the illustration, the parallelogram method is used. The diagonal of the parallelogram defined by  $\vec{F}_x$  and  $\vec{F}_y$  is  $\vec{F}_r$ , the vector indicating the magnitude and direction of the total force acting on the asteroid.  $\vec{F}_r$  is called the resultant of  $\vec{F}_x$  and  $\vec{F}_y$ .

Another useful vector is  $F_e$ , the equilibrant of  $\vec{F}_x$  and  $\vec{F}_y$ .  $\vec{F}_e$  is the force needed to exactly offset the combined pull of the two ships.  $\vec{F}_e$  has the same magnitude  $\vec{F}_r$ , the equilibrant provides a useful experimental method for finding the resultant of two or more forces.

### 3. EXPERIMENTAL PROCEDURE

#### Part A: Adding Forces; Resultants and Equilibrants:

1. Set up the equipment as shown in Fig.2.3. The mass Hanger and mass provide a gravitational force  $\vec{F} = m\vec{g}$  downward. However, since the Force Ring is not accelerated, the downward force must be exactly balanced by an equal and opposite, or equilibrant force. This equilibrant force,  $\vec{F}_e$ , is of course provided by the Spring Balance.

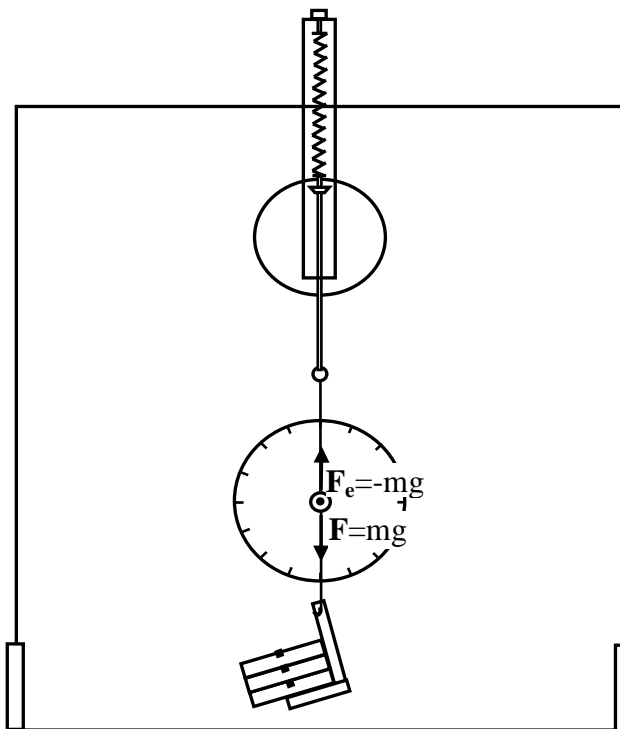


Figure 2.3: Equipment Setup

2. Now use pulleys and hanging masses as shown in Fig.2.4 to setup the equipment so that two forces,  $\vec{F}_1$  and  $\vec{F}_2$ , are pulling on the Force Ring. Use the Holding Pin to prevent the ring from being accelerated. The Holding Pin provides a force  $\vec{F}_e$  that is exactly opposite to the resultant of  $\vec{F}_1$  and  $\vec{F}_2$ .
3. Adjust the Spring Balance to determine the magnitude of  $\vec{F}_e$ . As shown, keep the Spring Balance vertical and use a pulley to direct the force from the springing the desired direction. Move the Spring Balance toward or away from the pulley to vary the magnitude

of the force. Adjust the pulley and Spring Balance so that the Holding Pin is centered in the Force Ring.

**NOTE:** To minimize the effects of friction in the pulleys, tap as needed on the Experiment Board each time you reposition any component. This will help the Force Ring come to its true equilibrium position.

Record the magnitude in newtons of  $\vec{F}_1$ ,  $\vec{F}_2$ , and  $\vec{F}_e$ ; the value of the hanging masses,  $M_1$ , and  $M_2$  (include the mass of the mass hangers); and also  $\theta_1$ ,  $\theta_2$ , and  $\theta_e$ , the angle each vector makes with respect to the zero-degree line on the degree scale.

4. Vary the magnitudes and directions  $\vec{F}_1$  of and  $\vec{F}_2$  and repeat the experiment.

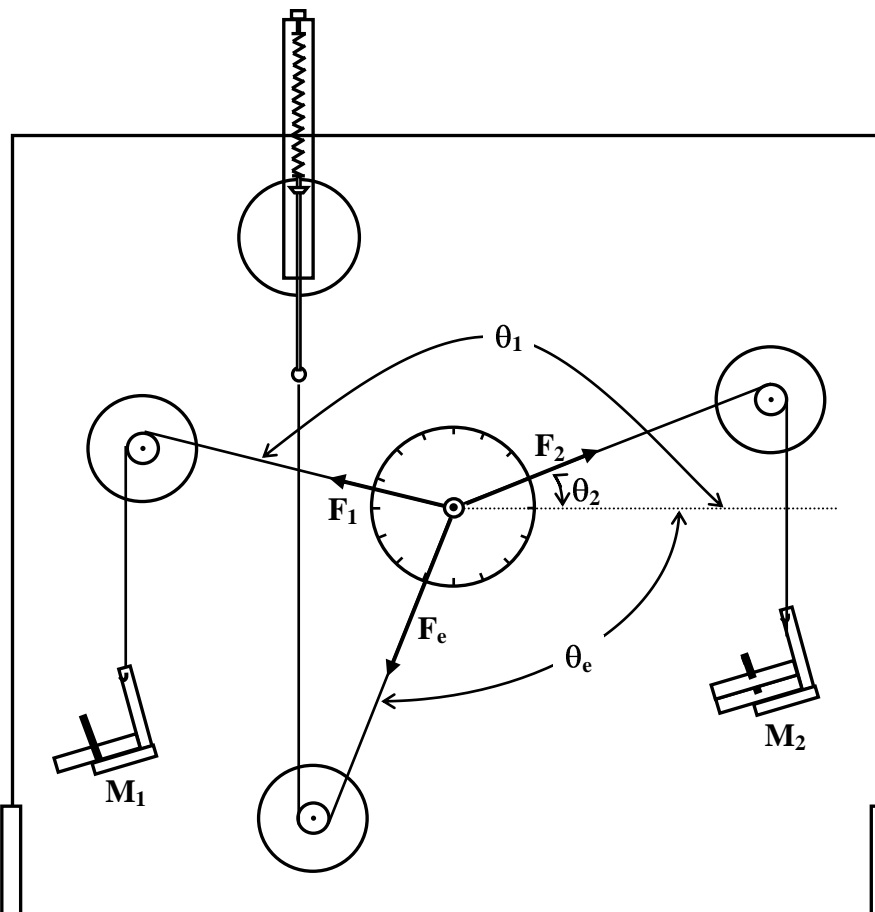


Figure 2.4: Equipment Setup

### Part B: The Resolving Force and Components:

Set up the equipment as shown in Fig. 2.5. As shown, determine a force vector,  $\vec{F}$ , by hanging a mass from the Force Ring over a pulley. Use the Holding Pin to hold the Force Ring in place.

1. Setup the Spring Balance and pulley so the string from the balance runs horizontally from the bottom of the pulley to the Force Ring. Hang a second Mass Hanger directly from the Force Ring.

Now pull the Spring Balance toward or away from the pulley to adjust the horizontal, or “x-component” of the force. Adjust the mass on the vertical Mass Hanger to adjust the vertical or “y-component” of the force. Adjust the x and y components in this way until the Holding Pin is centered in the Force Ring. (Notice that these x and y components are actually the x and y components of the equilibrant of  $\vec{F}$ , rather than of  $\vec{F}$  itself.)

**NOTE:** The hanging masses allow the mass to be varied only in 10 gr increments. Using an additional Mass Hanger as a mass allows adjustments in 5 gr increments. Paper clips are convenient for more precise variation. Weigh a known number of clips with the Spring Balance to determine the mass per clip.

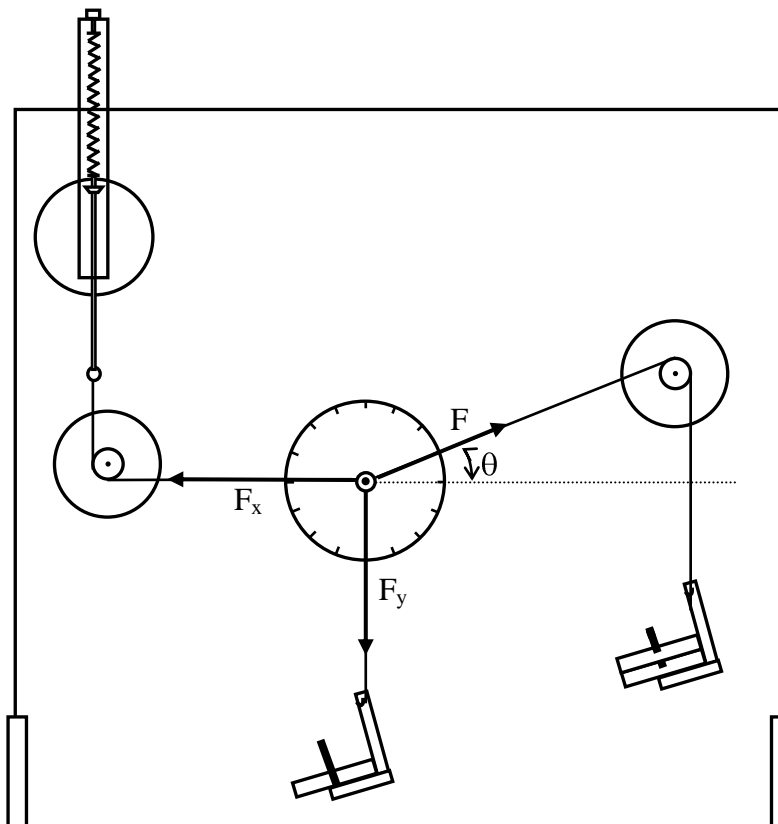


Figure 2.5: Equipment Setup

2. Record the magnitude and angle of  $\vec{F}$ . Measure the angle ( $\theta$ ) as shown in Fig.2.5.
3. Record the magnitude of the x and y components of the equilibrant of  $\vec{F}$ .
4. Change the magnitude and direction of  $\vec{F}$  and repeat the above steps.
5. Record the angle of  $F(\theta)$ , and the magnitudes of  $\vec{F}$ ,  $\vec{F}_x$ , and  $\vec{F}_y$ .
6. Setup the equipment as in the first part of this experiment, using a pulley and hanging mass to establish the magnitude and direction of a force vector. Be sure the x-axis of the Degree Plate is horizontal.
7. Record the magnitude and angle ( $\theta$ ) of the vector  $\vec{F}$  that you have constructed.
8. Now setup the Spring Balance and a hanging mass, as in the first part of this experiment (Fig.2.5). Using the values you calculated in question 7, position the Spring Balance so it pulls the Force Ring horizontally by an amount  $\vec{F}_x$ . Adjust the hanging mass so it pulls the Force Ring vertically down by an amount  $\vec{F}_y$ .

Generally it is useful to find the components of a vector along two vertical axes as you did above. However, it is not necessary that the x and y axes are perpendicular. If time permits, try setting up the equipment to find the components of a vector along non-perpendicular axes. (Use pulleys to redirect the component forces to non-perpendicular directions.)

#### 4. DISCUSSIONS AND CONCLUSIONS

1. What is the magnitude and direction of  $F$ , the gravitational force provided by the mass and Mass Hanger ( $\vec{F} = m \vec{g}$ ) using Fig. 2.3.
2. Use the Spring Balance and the Degree Plate to determine the magnitude and direction of  $\vec{F}_e$  using Fig. 2.3.
3. Use the values you recorded above to construct  $\vec{F}_1$ ,  $\vec{F}_2$ , and  $\vec{F}_e$  on a separate sheet of paper. Choose an appropriate scale (such as 1.0 mm/Nt) and make the length of each vector proportional to the magnitude of the force. Label each vector and indicate the magnitude of the force it represents.
4. On your diagram, use the parallelogram method to draw the resultant of  $\vec{F}_1$  and  $\vec{F}_2$ . Label the resultant  $\vec{F}_r$ . Measure the length of  $\vec{F}_r$  to determine the magnitude of the resultant force and record this magnitude on your diagram.

- Does the equilibrant force vector,  $\vec{F}_e$ , exactly balance the resultant vector,  $\vec{F}_r$ . If not, can you suggest some possible sources of error in your measurements and constructions?
- What are the magnitudes of  $\vec{F}_x$  and  $\vec{F}_y$ , the x and y components of  $\vec{F}$ ?

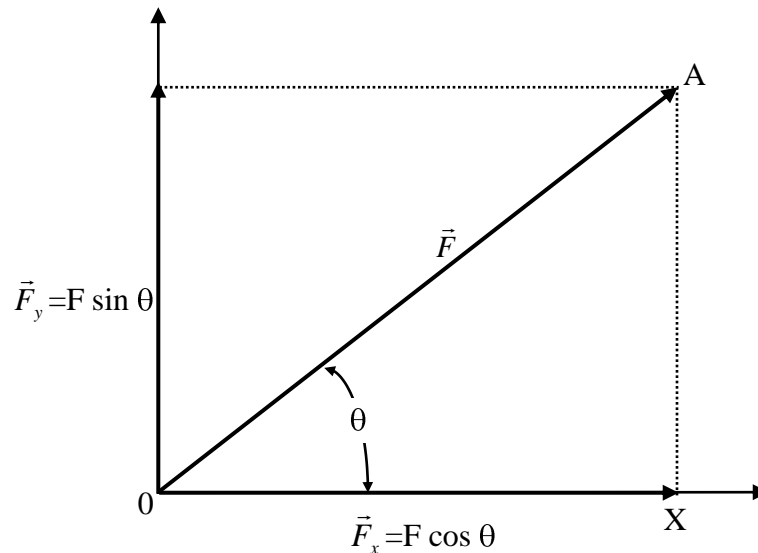


Figure 2.6: Vector Components

- Why use components to specify vectors? One reason is that using components makes it easy to add vectors mathematically. Fig. 2.6 shows the x and y components of a vector of length  $\vec{F}$ , at an angle  $\theta$  with the x-axis. Since the components are at right angles to each other, the parallelogram used to determine their resultant is a rectangle. Using right triangle AOX, the components of  $\vec{F}$  are easily calculated: the x-component equals  $F \cos \theta$ ; the y-component equals  $F \sin \theta$ . If you have many vectors to add, simply determine the x and y components for each vector. Add all the x-components together and add all the y-components for the resultant.
- Calculate  $\vec{F}_x$  and  $\vec{F}_y$ , the magnitudes of the x and y components of  $\vec{F}$  ( $\vec{F}_x = F \cos \theta$ ;  $\vec{F}_y = F \sin \theta$ ).
- Is the Force Ring at equilibrium in the center of the Degree plate?
- What difficulties do you encounter in trying to adjust the x and y components to resolve a vector along non-perpendicular axes?

## 5. QUESTIONS

1. Find an expression or procedure for finding the length of a vector with components along x, y, and z axes.
2. If a vector has a magnitude of 18 and an x component  $-7.0$ , what are the two possibilities for its y component and direction?
3. Can two vectors of different magnitude be combined to give a zero resultant? Can three vectors?
4. Can a vector have zero magnitude if one of its components is not zero?
5. If three vectors add up to zero, they must all be in the same plane. Make this plausible.





**GENERAL PHYSICS  
PART A: MECHANICS  
EXPERIMENT – 3**

**EQUILIBRIUM OF PHYSICAL BODIES AND THE PRINCIPLE OF  
TORQUES AND CENTER OF MASS**

### **1. PURPOSE**

To determine the conditions for equilibrium of a rigid body under the action of a system of coplanar parallel forces; to study the principle of moments and the center of mass.

### **3. THEORY**

Gravity is a universal force; every bit of matter in the universe is attracted to every other bit of matter. So when the balance beam is suspended from a pivot point, every bit of the matter in the beam is attracted to every bit of matter in the Earth.

Fortunately for engineers and physics students, the sum of all these gravitational force produces a single resultant. This resultant acts as if it were pulling between the center of the Earth and the center of the mass of the balance beam. The magnitude of the force is the same as if all the matter of the Earth were located at the center of the Earth, and all the matter of the balance beam were located at the center of mass of the balance beam. In this experiment, you will use your understanding of torque to understand and locate the center of mass of an object.

Since the lines of action of the forces all passed through the same point, there was no turning effect on the body. Any unbalanced force would merely cause a linear acceleration. However, if a rigid body is acted upon by a system of forces which are not concurrent, there may result either a linear acceleration, or an angular acceleration (or both) unless the magnitudes, lines of action, and points of application of the forces are so chosen as to produce equilibrium. In this experiment you will investigate the interplay between forces and torques by examining all the forces acting on a body in physical equilibrium.

**Moment:** The turning effect of a force is called moment. The word torque is also used in this connection. The moment of a force is defined as the product of the force times the perpendicular distance from the axis of rotation to the line of action of the force. A moment is said to be clockwise (considered negative) if its effect would be to rotate the body clockwise and counter-clockwise (positive)

**Rigid Body:** A rigid body is one which will transmit a force undiminished throughout its mass. The particles of a rigid body do not change positions with respect to one another. A rigid body is in equilibrium when both its linear acceleration and its angular acceleration are zero. The two conditions for equilibrium of a coplanar force system may be stated as follows.

**First condition:** The vector sum of all forces acting on the body must be zero. Mathematically,

$$\sum \vec{F} = 0 \quad (3.1)$$

**Second condition:** The algebraic sum of all moments about any axis (within or outside the body) must be zero.

$$\sum \vec{M}_p = 0 \quad (3.2)$$

where p may be any point in the plane of the forces, whether inside or outside the rigid body.

### 3. EXPERIMENTAL PROCEDURES

#### A-) Center of Mass:

1. Hang the balance beam from the pivot as shown in Fig.3.1. Use the inclined plane as a level and straight edge to draw a horizontal reference line. Adjust the position of the balance beam in the pivot so that the beam balances horizontally.

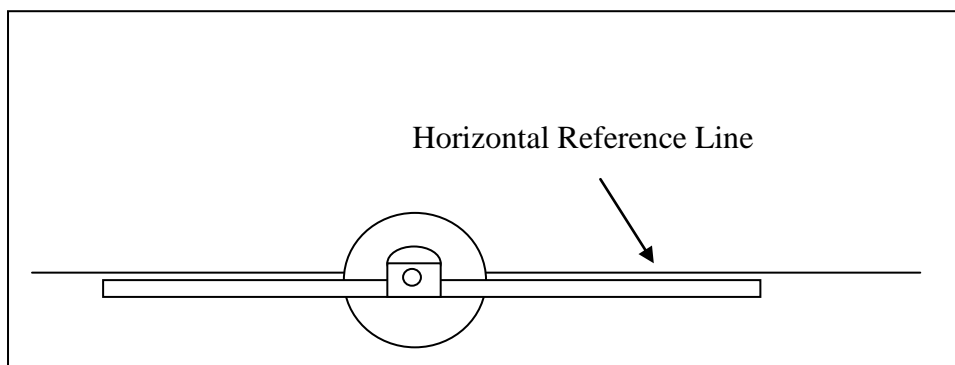


Figure 3.1: Equipment Setup

2. Since the balance beam is not accelerated, the force at the pivot point must be the equilibrant of the total gravitational force acting on the beam. Since the beam does not rotate, the gravitational force and its equilibrant must be concurrent force.
3. Think of the balance beam as a collection of many small hanging masses. Each hanging mass is pulled down by gravity and therefore provides a torque about the pivot point of the balance beam.

- Attach a mass hanger to each end of the beam. Hang 50 grams from one hanger, and 100 grams from the other, as shown in Fig. 3.2. Now slide the beam through the pivot retainer until the beam and masses are balanced and the beam is horizontal. The pivot is now supporting the beam at center of the mass of the combined system (i.e. balance beam plus hanging masses).

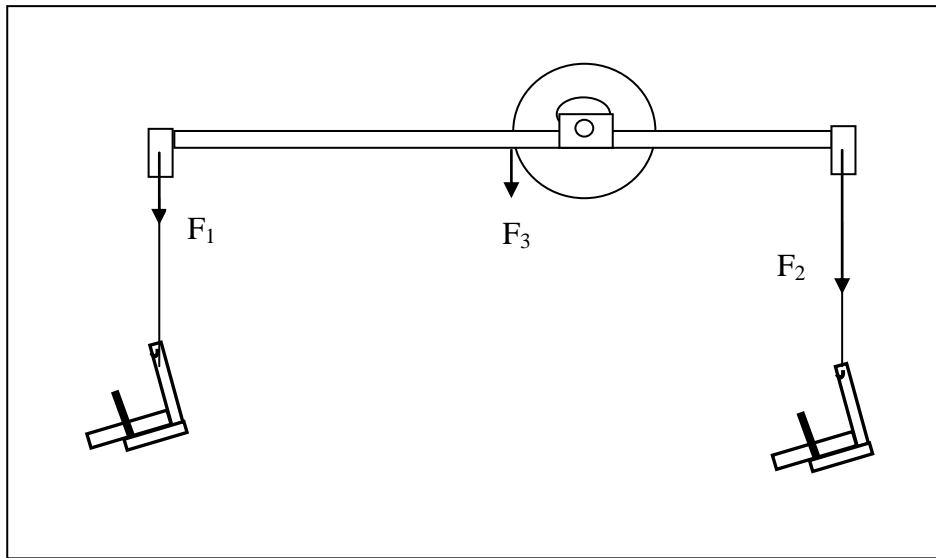


Figure 3.2: Torques and center of mass

- Remove the 50 gram mass and mass hanger. Reposition the beam in the pivot to relevel the beam. Recalculate the torques about the pivot point.
- Hang the planar mass from the holding pin of the degree plate as shown in Fig.3.3. Since the force of the pin acting on the mass is equilibrant to the sum of the gravitational forces acting on the mass, the line of the force exerted by the pin must pass through the center of the mass of the planar mass. Hang a piece of string with a hanging mass from the holding pin.
- Tape a piece of paper to the planar mass as shown Fig.3.3. Mark the paper to indicate the line of the string across the planar mass. Now hang the planar mass from a different point. Again, mark the line of the string. By finding the intersection of the two lines, locate the center of mass of the planar mass.
- Hang the planar mass from a third point.

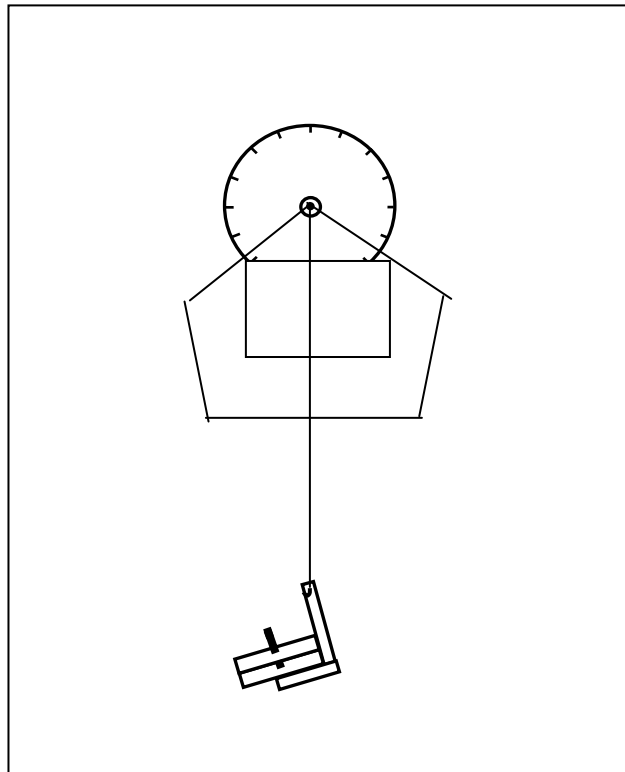


Figure 3.3: Finding the center of mass

**B. Equilibrium of Physical Bodies:**

1. Fig.3.4 shows three spaceships pulling on an asteroid. Which way will the asteroid move? Will it rotate? The answers to these questions depend on the total force and the total torque acting on the asteroid. But any force acting on a body can produce both translational motion (movement of the center of the mass the body in the direction of the force) and rotation. In this experiment you will investigate the interplay between forces and torques by examining all the forces acting on a body in physical equilibrium.

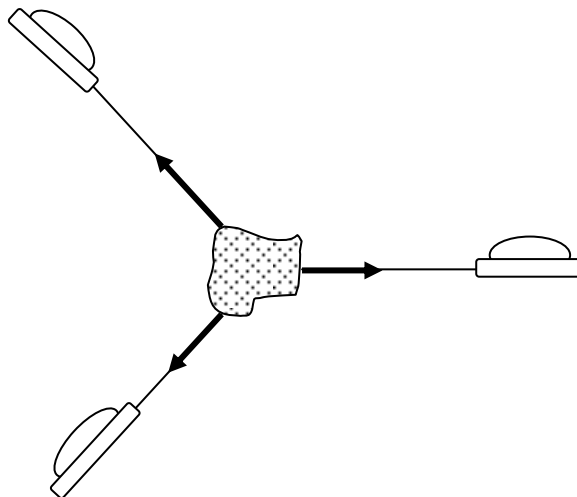


Figure 3.4: Non-Concurrent, Non-Parallel Forces

2. Using the technique described in part a, find the center of mass of the balance beam, and mark it with a pencil. Then set up the equipment as shown in Fig.3.5. (The retainer can be pulled from the pivot Mount and hung from the metal rings, as shown.) By supporting the balance beam from the spring balance, you can now determine all the forces acting on the beam. As shown in the illustration, these forces include:
  - 2.1.  $\vec{F}_1$  – the weight of the mass  $M_1$  (including the mass hanger and plastic retainer).
  - 2.2.  $\vec{F}_2$  – the weight of mass  $M_2$  (including the mass hanger and plastic retainer).
  - 2.3.  $\vec{F}_3$  – the weight of the balance beam, acting through its center of mass.
  - 2.4.  $\vec{F}_4$  – the upward pull of the spring balance (minus the weight of the plastic retainer).
3. Fill in Table 2, listing  $M$  (the masses in grams),  $\vec{F}$  (the magnitude of the forces in newtons),  $d$  (the distance in millimeters from the applied force to the point of suspension), and  $\tau$  (the torques acting about the point of suspension in newtons x millimeters). Indicate whether each torque is clockwise (cw) or counterclockwise (ccw).

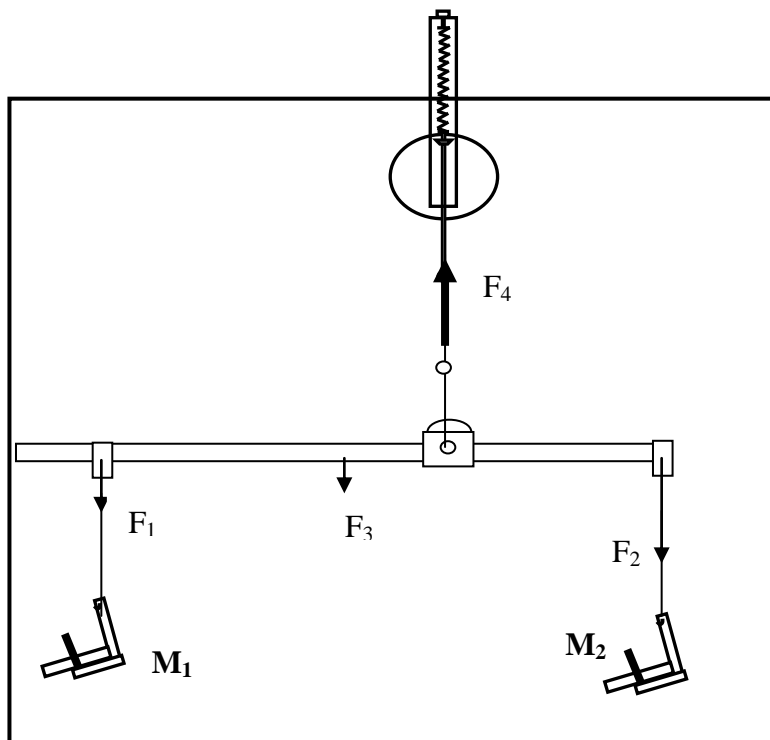


Figure 3.5: Equipment Setup

4. In measuring the torques, all distances were measured from the point of suspension of the balance beam. This measures the tendency of the beam to rotate about this point of suspension. You can also measure the torques about any other point, on or off the balance beam. Using the same forces as you used in Table 2.2 above, remeasure the distances, measuring from the left end of the balance beam as shown in Fig. 3.6. Then recalculate the torques to determine the tendency of the beam to rotate about the left end of the beam. Record your data in Table 2.3. As before, indicate whether each torque is clockwise (cw) or counterclockwise (ccw).

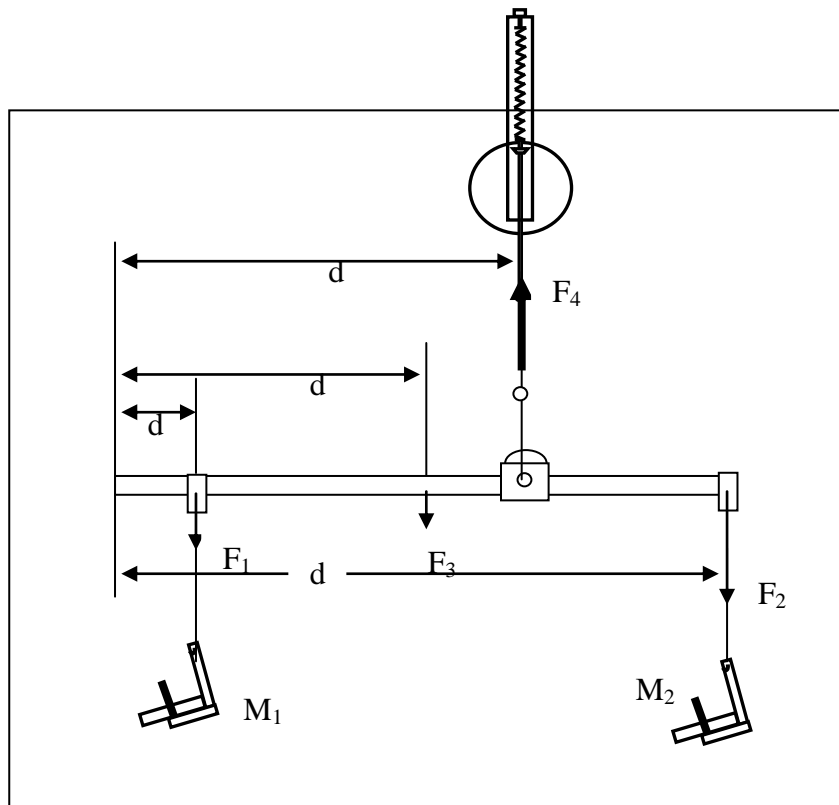


Figure 3.6: Changing the origin

5. Use a pulley and a hanging mass to produce an additional upward force at one end of the beam (You may need to use tape to secure the string to the beam, to avoid slippage). Adjust the positions of the remaining hanging masses and the spring balance on the beam until the beam is balanced horizontally.

## 4. DISCUSSIONS AND CONCLUSIONS

### A-) Center of Mass:

1. Why would the balance beam necessarily rotate if the resultant of the gravitational forces and the force acting through the pivot were not concurrent forces?
2. What is the relationship between the sum of the clockwise torques about the center of mass and the sum of the counterclockwise torques about the center of mass? Explain.
3. Calculate the torques,  $\tau_1$ ,  $\tau_2$ , and  $\tau_3$  provided by the forces  $\vec{F}_1$ ,  $\vec{F}_2$ , and  $\vec{F}_3$  acting about the new pivot point, as shown in Fig.3.2. Be sure to indicate whether each torque is clockwise (cw) or counterclockwise (ccw).
4. Are the clockwise and counterclockwise torques balanced?
5. Are the torque balance according to the experimental procedure part five?
6. Does the line of the string pass through the center of mass according to the experimental procedure part seven and eight?
7. Would this method work for a three dimensional object? Why or why not?

### B. Equilibrium of Physical Bodies:

1. Calculate and record the sum of the clockwise and counterclockwise torques. Are the torques balanced?
2. Calculate the sum of the upward and downward forces. Are these translational forces balanced?
3. On the basis of your answers to questions 1 and 2, what conditions must be met for a physical body to be in equilibrium (no acceleration)?
4. Calculate and record the sums of the clockwise and counterclockwise torques. Are the torques balanced according to the data taken experimental procedure part three ?
5. Are all the forces balanced, both for translational and rotational motion? Diagram your setup and show your calculations on a separate sheet of paper for experimental procedure part four.
6. From the data taken in this section, verify the first condition of equilibrium. Be sure to display your results in such a way tht your prof will be clear.
7. From the data taken in this section and using the second condition, determine the force contributed by unknown mass. Use the fulcrum as the center of moments. Compare this calculated result with the actual weight of the object. Do your results verify the principle of moment ?

- Compare your experimental results with the calculated results and Express the percent error, accepting the calculated results as being correct.

## 5. QUESTIONS

- Discuss the sources of error in the experiment. List and give a brief discussion of at least three structural components or machine components which are examples of a system of coplanar parallel forces in equilibrium.
- What is meant by a rigid body?
- What is the definition of the moment of a force?
- State the two conditions for equilibrium of a rigid body acted upon by a system of coplanar parallel forces.
- A large beam is to be supported by columns of steel at either end. The beam will support a floor on which heavy machinery is to be permanently installed. Is it necessary that the steel support columns be of equal strength? Explain.
- Give several examples of a body that is not in equilibrium, even though the resultant of all the forces acting on it is zero.
- A ladder is at rest with its upper end against a wall and the lower end on the ground. Is it more likely to slip when a man stands on it at the bottom or at the top? Explain.
- Do a center of mass and the center of gravity coincide for a building? For a lake? Under what conditions does the difference between the center of mass and the center of gravity of a body become significant?
- Explain, using forces and torques, how a tree can maintain equilibrium in a high wind.

**Table2.2:** Data table

$M_1$	$F_1$	$d_1$	$\tau_1$	$M_2$	$F_2$	$d_2$	$\tau_2$	$F_3$	$d_3$	$\tau_3$	$F_4$	$d_4$	$\tau_4$
-------	-------	-------	----------	-------	-------	-------	----------	-------	-------	----------	-------	-------	----------

**Table 2.3:** Data table

$M_1$	$F_1$	$d_1$	$\tau_1$	$M_2$	$F_2$	$d_2$	$\tau_2$	$F_3$	$d_3$	$\tau_3$	$F_4$	$d_4$	$\tau_4$
-------	-------	-------	----------	-------	-------	-------	----------	-------	-------	----------	-------	-------	----------





**GENERAL PHYSICS  
PART A: MECHANICS  
EXPERIMENT – 4  
VELOCITY AND ACCELERATION**

### 1. PURPOSE

The quantitative study of motion is a key element of physics. The simplest motion to describe is the motion of an object traveling at a constant speed in a straight line. In this lab you will furnish your own constant speeds and utilize the Smart Pulley for acquiring and processing data.

### 3. THEORY

The concept of speed and know that the speed of an object is measured in units such as miles per hour, kilometers per hour, or meters per second. The speed is the ratio of the distance traveled to the time required for the travel. We define the average speed as the total distance,  $x$  traveled during a particular time divided by that time interval  $t$ ;

$$\text{Average speed} = \text{total distance traveled} / \text{time interval for interval} = \frac{x}{t}$$

The definition deals only with the motion itself, in the same, other definitions in kinematics are restricted to properties of the motion only. If the average speed is the same for all of a trip, then the speed is constant.

In reality, motion is usually not restricted to one dimension, and we must take account of the direction as well as the speed of an object's motion. The name for the quantity that describes both the direction and the speed of motion is **velocity**. Even though we are considering only one-dimensional motion, we must still take account of direction) for example, positive versus negative, or east versus west), so we will use the term velocity. Suppose a car is located at point  $x_1$  at a time  $t_1$ , and at another point  $x_2$  at a later time  $t_2$ . Then the car's **average velocity**  $v$  over the time interval is

$$v = (\text{final position} - \text{initial position}) / (\text{final time} - \text{initial time}) = \frac{(x_2 - x_1)}{(t_2 - t_1)}$$

The average velocity is the displacement divided by the time elapsed during that displacement. In general, a bar over a symbol (as in  $v$ ) indicates the average value of that quantity, in this case the average velocity. Note that the average velocity can be either positive

or negative. The difference between speed and velocity is more than just an algebraic sign; it involves the difference between the total distance traveled (for speed) and the net change in position (for velocity).

If the velocity of a moving body does not change with respect to time, the body's motion is called "uniform". The instantaneous velocity of a moving particle at a particular time  $t$  is given by

$$\vec{v} = \frac{d\vec{x}}{dt} \quad (4.1)$$

where  $\mathbf{x}$  is the displacement vector.

We defined the average velocity of an object as its change in position divided by the time elapsed,  $v = \Delta x / \Delta t$ . This tells us how the object's position changes with time. It is reasonable to define a quantity that indicates how the object's velocity changes with time. We define the **average acceleration**,  $a$ , as the change in velocity divided by the time required for the change. The average acceleration can be written as

$$a = \frac{(v_2 - v_1)}{(t_2 - t_1)} = \frac{\Delta v}{\Delta t} \quad (4.2)$$

According to Newton's first law, an object set in motion on a perfectly smooth, level, frictionless surface continues to move in a straight line with constant velocity. If the velocity of a moving object changes in time either in magnitude or direction, the object is said to be in accelerated motion. The instantaneous acceleration at time  $t$  is given by

$$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d^2\mathbf{x}}{dt^2} \quad (4.3)$$

According to Newton's second law, when a force is applied to an object it experiences an acceleration which is proportional in magnitude to the applied force, in the direction of the force. This relation is expressed as

$$\vec{F} = m\vec{a} \quad (4.4)$$

where  $m$  is the mass of the object.

### 3. EXPERIMENTAL PROCEDURE

#### Part A: Constant Velocity

- 1- Set up the apparatus as show in Fig. 4.1, in an area where you can pull the thread 50-100 cm in a straight line. Connect the Smart Pulley to your Apple II.
- 2- Insert The Smart Pulley software disk drive and start up the computer.

- 3- The computer will ask you to specify how the Smart Pulley is connected. Ask your instructor for the correct response, select it, then press <RETURN>.
- 4- When you have gotten to the main menu, select option <M>, the motion timer. In this mode, the computer will measure and record up to 200 time intervals as your pulley spins.
 

***Hint:*** To avoid getting extraneous times in your data when using option M, make sure your set up is ready to go and the red LED on the Smart Pulley is off before you press <RETURN>.

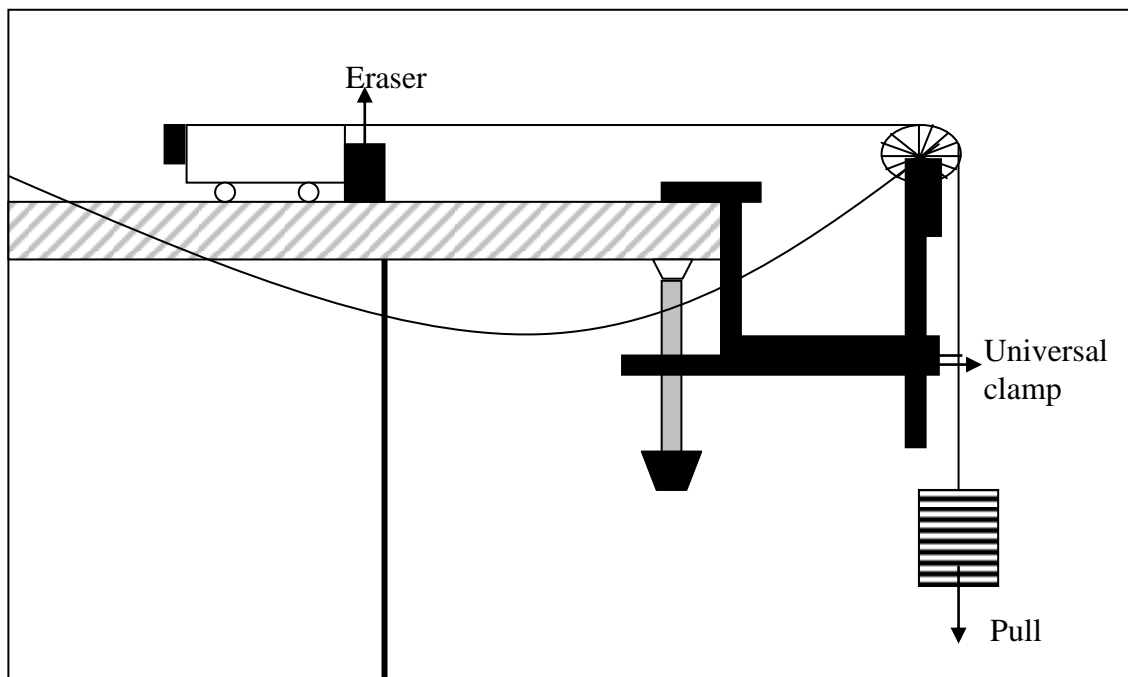


Figure 4.1: Equipment Setup

5. Now press <RETURN>. Let one person pull the thread at a constant speed; another should press on the eraser to establish enough tension to turn the pulley. As the thread runs out, press <RETURN> to halt the timing process. <RETURN>.
6. When the computer finishes its calculations, it will display the measured times. Press the space bar on the keyboard to scroll through the data. When you reach the bottom of the table, press <RETURN> to move to the next menu.
7. At the next menu, choose option <G> to enter the grapping mode, then choose <A> to tell the computer you are using the Smart Pulley to monitor a linear motion. When you get to the grapping menu, choose <D> to select a distance-time graph.

8. In the next menu, choose <G>, then press the space bar so your graph will have a grid. Also press <P> followed by <SPACE BAR> so your graph will not have point protectors. Pressing <RETURN> starts the actual graphing routine.
9. Examine the graph, then press <RETURN>. You will be shown a new menu. If your graph shows reasonably constant speed, press <T> to see the data.
10. Now choose option <A> from the same menu, so you can alter the style of the graph. Choose a velocity-time graph by pushing <V> to display the velocity and time information. Record the first 25 velocities in your data table.

### Part B: Acceleration

- 1- Set up the apparatus as shown in Fig. 4.2, in an area where the cart move 1-2 meters in a straight line. Connect the Smart Pulley to your Apple II.

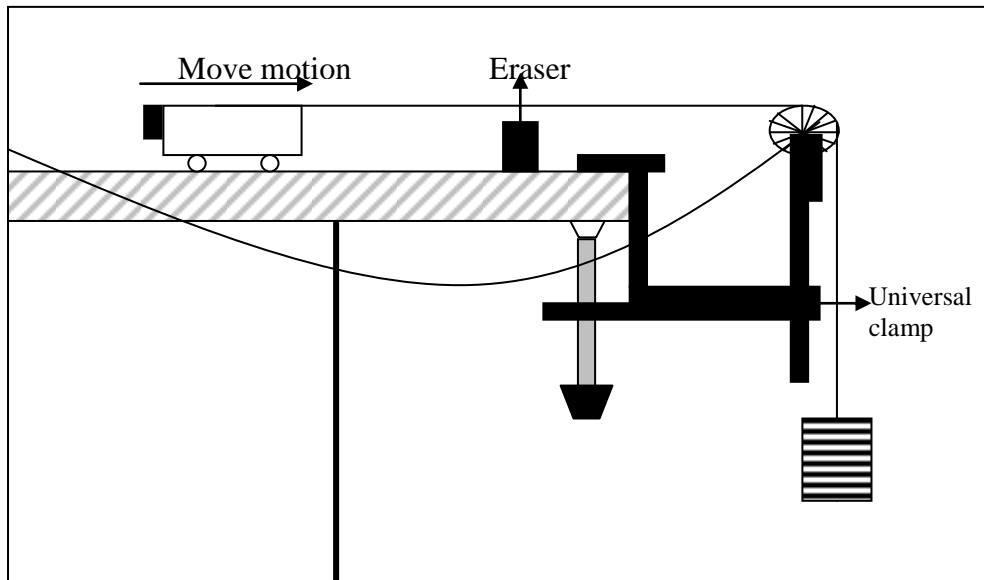


Figure 4.2: Equipment Setup

- 2- When you have gotten to the main menu, select option <M>, the motion timer. In this mode, the computer will measure and record up to 200 time intervals as your pulley spins.  
***Hint:*** To avoid getting extraneous times in your data when using option <M>, make sure your set up is ready to go and the red LED on the Smart Pulley is off before you press <RETURN>.
- 3- Now press <RETURN> on the computer. Release the mass hanger which fall downward, pulling to cart across the table. Stop the timing just before the mass hanger reaches the floor by pressing <RETURN>.

- 4- When the computer finishes its calculations, it will display the measured times. Press the space bar on the keyboard to scroll through the data. When you reach the bottom of the table, press <RETURN> to move to the next menu.
- 5- At the next menu, choose option <G> to enter the graphing mode, then choose <A> to tell the computer you are using the Smart Pulley to monitor a linear motion. When you get to the graphing menu, choose <D> to select a distance-time graph.
- 6- In the next menu, choose <G>, then press the space bar so your graph will have a grid. Also press <P> followed by <SPACE BAR> so your graph will not have point protectors. Pressing <RETURN> starts the actual graphing routine.
- 7- Examine the graph, then press <RETURN>. You will be shown a new menu. If your graph shows reasonably constant speed, press <T> to see the data.
- 8- Now choose option <A> from the same menu, so you can alter the style of the graph. Choose a velocity-time graph by pushing <V> to display the velocity and time information. Record the first 25 velocities in your data table.

#### **4. DISCUSSIONS AND CONCLUSIONS**

1. Construct a graph showing, Distance (vertical axis), Time (horizontal axis). Construct a second graph showing Velocity (vertical axis) versus Time. Be prepared to discuss the two graphs.
2. In your write-up, include a description of the motion, a description of the graphs that you obtained, and try to generalize on what the different shapes of graphs mean of the motion they describe.
3. Sketch a curve of velocity versus time for the displacement-time curve. Sketch the acceleration-time curve also.
4. Sketch graphs to represent the following assumptions: (a) A car driven for 1 hour at a constant speed of 37 km/h, (b) A person runs as fast as possible to the corner mailbox and immediately runs back as fast as possible.
5. Determine the average velocity and the average acceleration using the graphs.

#### **5. QUESTIONS**

1. What are significant sources of error in this experiment?
2. Theoretically what should be the shape of the graph of part A? Is it so? If not, what factors may have caused this deviation from the expected shape?

3. Considering the time intervals to be errorless, calculate the percentage error in the velocity measured by you?
4. If the maximum error in the time intervals is %10, what is the % error in the measured acceleration?
5. In trying to determine an instantaneous velocity, what factors (timer accuracy, object being timed, type of motion) influence of the measurement? Discuss how each factor influences the result.
6. Can you think of one or more ways to measure instantaneous velocity, or is an instantaneous velocity always a value that must be inferred from average velocity measurements?
7. Can you think of physical phenomena involving the earth in which the earth cannot be treated as a particle?
8. Each second a rabbit moves half the remaining distance from his nose to a head of lettuce. Does he ever get to the lettuce? What is the limiting value of his average velocity? Draw graphs showing his velocity and position as time increases.
9. Average speed can mean the magnitude of the average velocity vector. Another meaning given to it is that average speed is the total length of path traveled divided by the elapsed time. Are these meanings different? If so, give an example.
10. When the velocity is constant, does the average velocity over any time interval differ from the instantaneous velocity at any instant
11. Can an object have an eastward velocity while experiencing a westward acceleration?
12. Can the direction of the velocity of a body change when its acceleration is constant?
13. Can a body be increasing in speed as its acceleration decreases? Explain.





**GENERAL PHYSICS  
PART A: MECHANICS  
EXPERIMENT – 5  
FREELY FALLING OBJECT**

### **1. PURPOSE**

The purpose of this laboratory is to determine the acceleration of gravity by timing the motion of a freely falling object.

### **2. THEORY**

The most common example of motion with (nearly) constant acceleration is that of a body falling toward the earth. In the absence of air resistance we find that all bodies, regardless of their size, weight, or composition, fall with the same acceleration at the same point on the earth's surface, and if the distance covered is not too great, the acceleration remains constant throughout the fall. This ideal motion, in which air resistance and the small change in acceleration with altitude are neglected, is called "free fall". The acceleration of a freely falling body is called the acceleration due to gravity and denoted by the symbol  $\bar{g}$ . Near the earth's surface its magnitude is approximately  $9.8 \text{ m/sec}^2$ , which  $980 \text{ cm/sec}^2$ , and it is directed down toward the center of the earth.

Up to now, the relationships between kinematics quantities such as velocity and acceleration were not dependent upon any property of nature, but rather on how they were defined. Here, for the first time, we have introduced a quantity, the acceleration of gravity, which reflects a property of nature. We cannot calculate the acceleration of gravity from just our knowledge of the kinematical relationships but rather it must be measured. The value we measure depends on the coordinate system and, hence, the units of measurement. But the fact that all things fall with the same acceleration (in the absence of air friction) is a consequence of natural law.

The acceleration of gravity near the earth's surface is slightly different at different location on earth. The acceleration depends on latitude because of the earth's rotation. It also depends on altitude. But for any given location, the acceleration there is the same for all objects.

The force of gravity at the same rate. Strictly speaking, such experiments must be conducted in a vacuum so that the force of air resistance does not affect the results. For relatively small, smooth bodies of considerable density, however, the error introduced by conducting such experiments in the atmosphere is quite small.

In any motion problem it should be apparent that three variables- distance, rate, and time- are involved. If the motion uniform, or if the concept of average velocity is used, the motion can be described by the simple equation

$$x=vt \quad (5.1)$$

where  $x$  is distance traveled in time  $t$  and  $v$  is the average velocity for the time interval  $t$ . When motion is non-uniform, that is, where velocity is changing, acceleration is said to take place. If the acceleration is uniform, as from a constant force such as the force of gravity, the acceleration can be defined as the average rate of change of velocity and it is given by the following equation:

$$a = \frac{(v_2 - v_1)}{t} \quad (5.2)$$

where  $v_2-v_1$  represents the change in velocity which occurs in time  $t$ . If a body starts from rest (i.e., $v=0$ ) and is uniformly accelerated by a constant force for a time interval  $t$ , the total distance it will travel is given by the equation

$$x = \frac{1}{2}at^2 \quad (5.3)$$

For the case of a body falling from a height  $h$  under the influence of the acceleration of gravity  $g$ , becomes

$$h = \frac{1}{2}at^2 \text{ and } v^2-v_o^2=2gh. \quad (5.4)$$

In this experiment, the “picket fence” included with the Smart Pulley system has evenly spaced black bars on a piece of clear plastic. When dropped through the photo gate, the bars interrupt the light beam. By measuring the distance between bars, and using the time measurements of the Smart Pulley, the acceleration of the freely picket fence can be calculated.

Note: On using the ”Picket Fence”

- a. When performing free-fall experiments, place a soft pad under the experiment to cushion the fall of the “Picket Fence”, or make sure to catch the bar to keep it from breaking.
- b. For accurate results drop the “Picket Fence” through the Smart Pulley Photo gate vertically as shown in Fig. 5.1.

- c. To achieve vertical alignment of the “Picket Fence” hold it between your thumb and forefinger, centered at the top of the bar, before releasing (See Fig. 5.2).

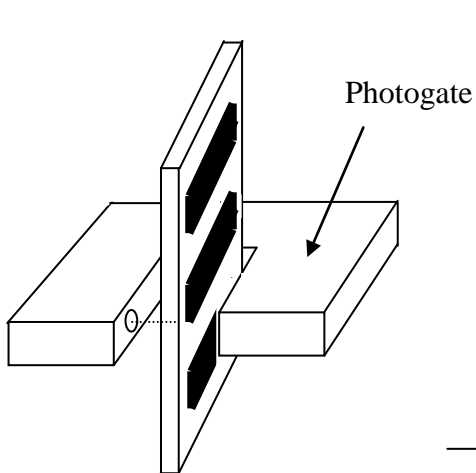


Figure 5.1: Picket Fence

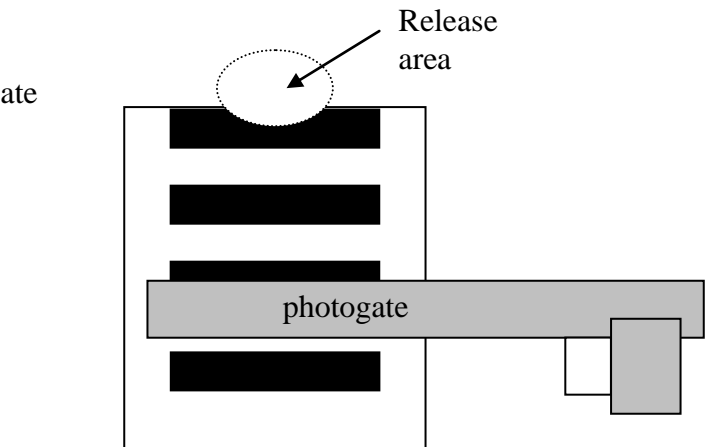


Figure 5.2: Picket Fence

### 3. EXPERIMENTAL PROCEDURE

1. Set up the apparatus as in Fig. 5.3. Measure  $\Delta d$ , the distance between the leading edges of adjacent bars on the picket fence, as shown. Record  $\Delta d$ .

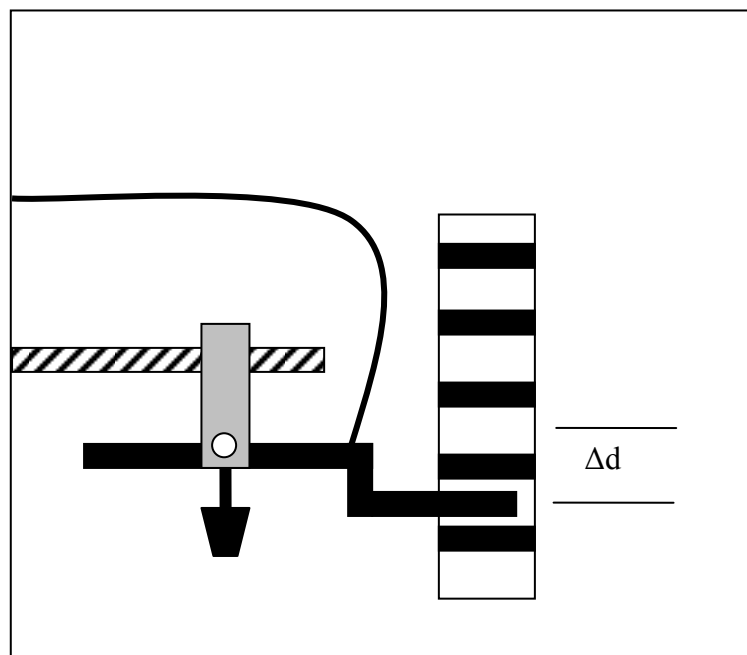


Figure 5.3: Equipment setup

2. Connect the Smart Pulley to your computer. Make sure the proper connections have been made before going on. Insert the Smart Pulley software disk into your computer disk drive and start up the computer.

3. The computer will ask you how the Smart Pulley is connected. Ask your instructor for the correct response, select it, then press <RETURN>.
4. From the Main Menu, select option <M>, but do not press <RETURN>.
5. Hold the picket fence in the gap between the arms of the photogate, as shown in Figure 3. Position the picket fence so that the photogate beam passes through a clear area, so the LED on top of the photogate is not lighted.
6. Now press <RETURN>. Drop the picket fence, being sure to catch it before it hits the floor. Press <RETURN> again to halt the timing process of the computer.
7. When the computer finishes its calculations, it will present you with a menu of data analysis options. Choose <G> to move to the graphing function, then choose <C> to tell the computer that you are monitoring the motion of the picket fence. When you get to the graphing menu, choose <V> which will give you a velocity-time graph.
8. You will now be asked to specify the style of the graph you want. Select <R>,<G> and <S>. (Remember, you must use the space bar so that ON appears to the left of each selection). The letter S indicates that statistical data will be displayed along with the graph. At the top of the graph you will see three numbers. They are:

M= slope of the graph

B= y-direction

R= correlation coefficient (how close the graph is to a straight line)

9. If your graph is a good straight line (as theory says it should be), record the slope of the graph, which is the acceleration, in Table 5.2. Its units are meter/sec<sup>2</sup>.
10. When finished looking at the graph, press <RETURN>. You will now be given several choices. If you are pleased with the graph you obtained, you should press <T> to get a readout of the data from your experiment. Copy the velocities and times into Table 5.1 or follow instructions for printing the data out on a printer.
11. Repeat the experiment at least 5 times. Select <X> to return to the Main Menu, then repeat steps 4-8. You need to record velocities and times for only one of your runs, but record the acceleration for each run.

#### **4. DISCUSSIONS AND CONCLUSIONS**

1. Use your data (from one run) to construct a velocity (vertical axis) versus time graph.
2. Average the acceleration from all of your runs.

3. Calculate the slope of your velocity-time graph. Analyze how close the several values for the acceleration of gravity were to each other. Analyze how close your average value was to the standard value of  $9.80 \text{ m/sec}^2$ .

## 5. QUESTIONS

- 1- What can be the sources of errors in your results?
- 2- Do you think that precise determinations of “ $\bar{g}$ ” on an area might give some evidences for the underground resources at that location?
- 3- Do you expect any dependence in the value of “ $\bar{g}$ ” on latitude and altitude of the location where the experiment is performed?

Distance per interval=  $\Delta d$ : ..... (assumed to be 0.050 m)

- 4- A ball thrown vertically upward rises to a maximum height and then falls to the ground. What are the ball's velocity and acceleration at the instant it reaches its maximum height?
- 5- A professor drops one lead sinker each second from a very high windows.(a) How far has the first sinker gone when the second one is dropped? (b) Does the distance between the first and second sinker remain constant? Explain your answer.
- 6- The equation  $v^2 - v_o^2 = 2gh$  was used to calculate the acceleration. Under what conditions is this equation valid? Are those conditions met in this experiment?
- 7- Could you use the relationship  $\vec{F} = m\vec{g}$  to determine the force acting between the earth and the moon? Explain.

<b>Table 5.1. Free-Fall Velocities and Times</b>					
Interval	Velocity	Total Time	Interval	Velocity	Total Time
1			11		
2			12		
3			13		
4			14		
5			15		
6			16		
7			17		
7			18		
8			19		
9			20		
10			21		

<b>Table 5.2. Free-Fall Acceleration</b>	
Trial	Acceleration
1	
2	
3	
4	
5	
6	
7	



**GENERAL PHYSICS  
PART A: MECHANICS  
EXPERIMENT – 6  
SPEED OF PROJECTILE**

**1. PURPOSE**

To determine the initial velocity of a projectile directly, using the Smart Pulley Photogate, and also by examining the motion of the projectile.

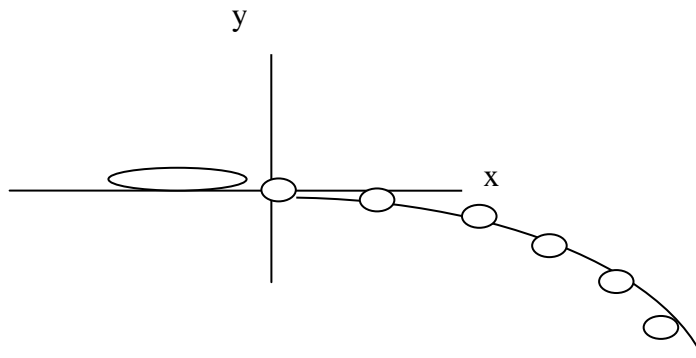
**2. THEORY**

Projectile motion adds a new dimensions, literally, to experiments in linear acceleration. Once a projectile is in motion, its acceleration is constant and in one direction only-down. But unless the projectile is fired straight up or down, it will have an initial velocity with a component perpendicular to the direction of acceleration. This component of its velocity, since it is perpendicular to the applied force of gravity, remains unchanged. Projectile motion is therefore a superposition of two relatively simple types of motion: constant acceleration in one direction, and constant velocity in an orthogonal direction.

A projectile is defined as any object in motion through space or through the atmosphere which no longer has a force propelling it. Thrown balls, rifle bullets, and falling bombs are examples of projectiles. Rockets and guided missiles are not projectiles while the propellant is burning, but become projectiles once the propelling force ceases to exist.

Consider an object, like a golf ball, projected horizontally (Fig.6.1). For the y (vertical) component of motion, the initial velocity is zero and the acceleration is that of gravity, giving

$$y = -\frac{1}{2}gt^2 \quad (6.1)$$



**Figure 6.1:** A photograph of a golf ball illuminated that given an initial horizontal velocity.



We use the minus sign because the acceleration of gravity is downward and we have chosen the upward direction to be positive in the figure. The projected objects starts at  $y=0$  and falls to negative values of  $y$ .

The horizontal component of motion has an initial velocity but is not accelerated, so

$$x = v_0 t \quad (6.1)$$

Solving this equation for  $t$  and inserting the value of  $t$  into the equation for  $y$ , we get

$$Y = -\frac{g}{2v_0^2} x^2 \quad (6.2)$$

This equation has the same form as the equation for a parabola. In both cases the factor that is multiplied by  $x^2$  on the right-hand side is a constant for a particular problem. Thus, we conclude that projectile motion is parabolic.

Now consider an object which is at the origin of the coordinate system at time  $t=0$ , and which has the initial velocity  $v_0$  making an angle  $\theta$  with the positive  $x$ -axis. There is no acceleration along the  $x$ -axis therefore the horizontal component of  $v_0$  remains constant in time and is

$$v_x = v_0 \cos \theta \quad (6.3)$$

Since there is acceleration along the negative  $y$ -axis,  $a_y = g \sin \theta$ , the  $y$ -component of  $v_0$  will change with time and is given by

$$v_y = v_0 \sin \theta - a_y t \quad (6.4)$$

The two coordinates of the object's position at any time  $t$  can be obtained by integrating equations (6.3) and (6.4).

$$x = (v_0 \cos \theta) t \quad (6.5)$$

$$y = (v_0 \sin \theta) t - \frac{1}{2} a_y t^2 \quad (6.6)$$

The two equations above are called parametric equations of the path of motion.

### 3. EXPERIMENTAL PROCEDURE

- 1- Set up the apparatus as shown in Fig. 6.2. Attach the photogate to your computer, insert the software disc, and turn on the computer.

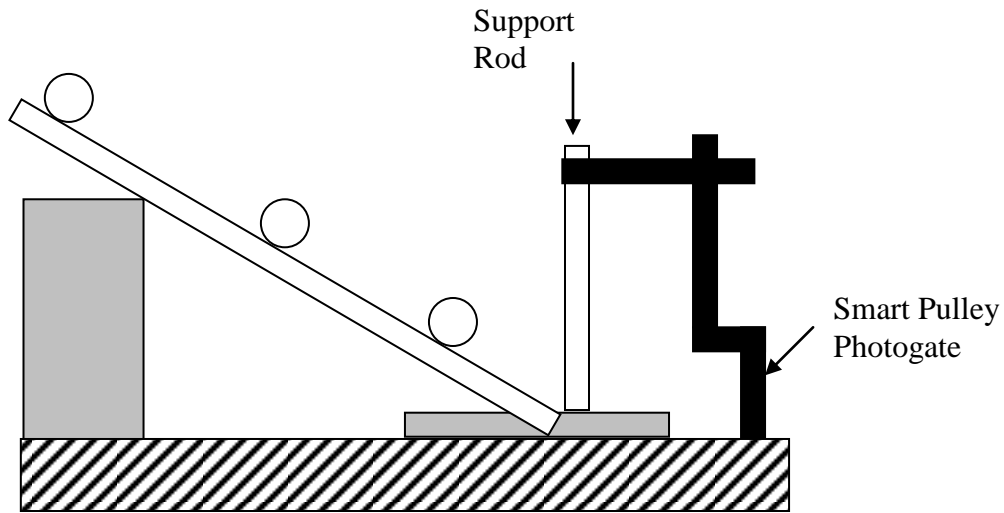


Figure 6.2: Equipment Setup

- 2- Place a piece of paper on the table, under the photogate. Remove the ramp, and use it to push the ball slowly through the photogate, as shown in Fig. 6.3. Determine the point at which the ball first triggers the photogate timer-this is the first point at which the LED turns ON- and mark it on the paper. Then determine the point at which the ball last triggers the timer, and mark this point also. Measure the distance between as  $\Delta d$ . Replace the ramp as in Fig. 6.2.
- 3- Choose option <G>, the gate function, from the Main menu. Now move the ball to a starting point somewhere on the ramp. Mark the starting position with a pencil so you will be able to repeat the run, starting the ball each time from the same point. Hold the ball at this position using a ruler or block of wood. Make sure the timer is not actively timing. Release the ball so that it moves along the ramp and through the photogate. Record the time in Table 6.1.
- 4- Repeat the trial at least five times with the same starting point and average the times you measure. Divide your distance  $\Delta d$  by the average measured time to calculate  $v_0$ , the velocity with which the sphere leaves the ramp.
- 5- Use a plumb bob to determine the point directly below where the ball leaves the edge of the table. The distance from the floor to the top of the table at the point where the ball leaves should be measured and recorded as  $d_y$ .
- 6- Now release the ball from your original starting spot, and note where it lands on the floor. This can be accurately determined by having the sphere hit a piece of carbon paper lying

over a piece of plain paper. The impact will leave a clear mark for measuring purposes. Repeat this at least 5 times.

- 7- Measure the average distance from the point directly below the ramp to the landing spot of your ball. Record this distance as  $d_x$ .

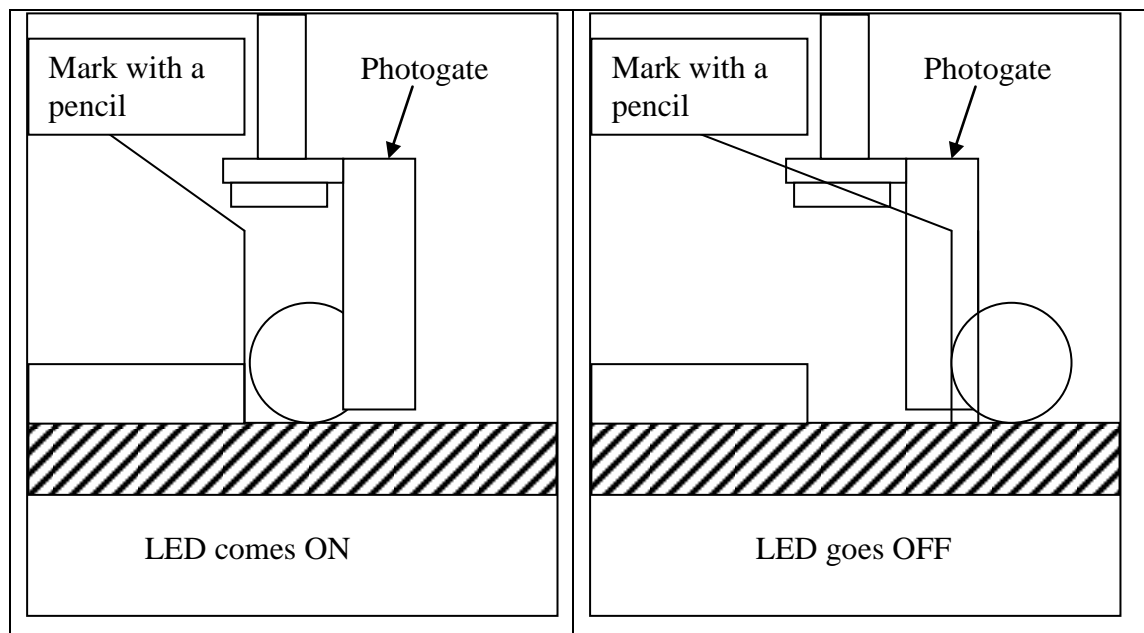


Figure 6.3: Measuring  $\Delta d$ .

#### 4. DISCUSSIONS AND CONCLUSIONS

The horizontal velocity of the sphere can be determined using the equations for projectile motion and your measured values for  $d_x$  and  $d_y$ . Calculate  $v_0$  in this manner and compare it to the value you obtained using the photogate timer. Report the two values and the percentage difference.

#### 5. QUESTIONS

- 1- What are the possible sources of error in this experiment?
- 2- For one of the trajectories, calculate the percentage error in  $v_0$ ,  $R$  and  $t_R$  assume the percentage error in the measurement of time to be 10%.
- 3- Is  $t_R = 2t_H$ ? Why?
- 4- Is the displacement of the mass along the x-axis constant for each time interval? Why?
- 5- For a given initial velocity, what should be the angle  $\theta$  to make  $R$  maximum?
- 6- Will a ball dropped from rest reach the ground quicker than one launched from the same height but with an initial horizontal velocity?

- 7- In projectile motion when air resistance is negligible, is it ever necessary to consider three-dimensional motion rather than two –dimension.
- 8- At what point in its path does a projectile have its minimum speed? Its maximum?

<b>Table 6.1: Measuring time</b>		
Trial	Time	Vertical height, $d_y = \dots$
1		Average horizontal distance, $d_x = \dots$
2		
3		
4		
5		
Ave. time		Horizontal velocity, $v_0 = \dots$
$V_0$ (Average)		Percentage difference = $\dots$



**GENERAL PHYSICS  
PART A: MECHANICS  
EXPERIMENT – 7**

**ACCELERATION OF A LABORATORY CART ( NEWTON’S SECOND LAW)**

### 1. PURPOSE

In this experiment, you will investigate the changes that occur with different masses hanging from the thread and with different masses being moved by the resulting forces.

### 2. THEORY

The study of the causes of motion is called dynamics. The laws that govern the motion of an object were described by Newton in 1657- known as Newton’s laws. The laws are physical interms of force and mass. Newton’s first law describes what happens when the net force acting on an object is zero. In that case, the object either remains at rest or continues in motion with constant speed in a straight line. If the net force on an object is zero then the objects acceleration is zero. If  $\sum \vec{F} = 0$  then  $\vec{a} = 0$ . And so the object remains at rest or at constant velocity. We used Newton’s 1<sup>st</sup> law in static,  $\sum \vec{F} = 0$ .

Newton’s second law describes the change of motion that occurs when a nonzero net force acts on the object. The original translation of **Newton’s second law** was, *The alteration of motion is ever proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed.* Elsewhere in the Principia Newton was clear that by “motion” he meant the product of the velocity and the mass. For the moment, it is sufficient to use Newton’s identification of mass as the “quantity of matter”. Then the second law:

The rate of change of momentum with time is proportional to the net applied force and is in the same direction:

$$\frac{\Delta(m\vec{v})}{\Delta t} = \sum \vec{F} \quad (7.1)$$

Where  $\sum \vec{F}$  is the net force – that is, the vector sum of all forces acting on a body- and the change in the momentum  $\Delta(m\vec{v})$  is in the direction of  $\sum \vec{F}$ .

In the majority of real situations, the mass of an object does not change appreciably, so the change in momentum is just the mass times the change in velocity. Then

$$\frac{\Delta(m\vec{v})}{\Delta t} = m \frac{\Delta\vec{v}}{\Delta t} = m\vec{a} \quad (7.2)$$

The rate of change in momentum of a body is proportional to the net force on the body. In equation from the 2<sup>nd</sup> law states.

$$\Sigma \vec{F} = m\vec{a} \quad (7.3)$$

This leads to the definition of force in terms of the acceleration of  $\vec{a}$  mass.

### 3. EXPERIMENTAL PROCEDURE

- 1- Set up the apparatus as shown in Fig.7.1 connect the Smart Pulley photogate to your computer, and start up the computer.

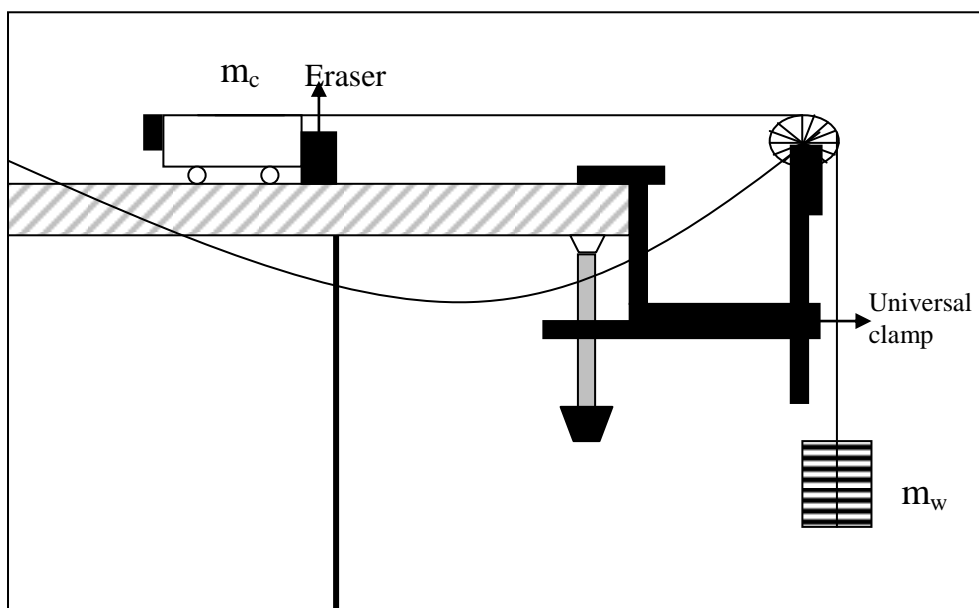


Figure 7.1: Equipment setup

- 2- Place a total of about 200 grams of mass on top of the cart and record the total mass of cart plus added mass as  $m_c$  in your Table 7.1. Place about 20 grams on the mass hanger. Including the mass of the mass hanger, record the total as  $m_w$ .
- 3- Move the cart backwards until the mass hanger almost touches the pulley. With the mass motionless, select <M> on the main menu.
- 4- Now press <RETURN> on the computer. Release the mass hanger which will fall downward, pulling the cart across the table. Stop the timing just before the mass hanger reaches the floor by pressing <RETURN>.
- 5- When the computer finishes converting the times, choose <G> which will move you to the graphing function. When you get to the graphing, select <A> which will interpret the timing as a linear motion. Choose <V> which will give you a velocity-time graph.

- 6- The next choices give you the style of graph wanted. Choose <S> to indicate that statistical data will be displayed along with the graph and <R> to plot the regression or best fit line. To choose these, move the cursor to the choices and push the <SPACE BAR> changing the “OFF” to an “ON” next to the choices. When completed, press <RETURN> to have the computer plot the graph.
- 7- At the top of the graph you should see three numbers. They are:
  - M--- The slope of the graph
  - B --- The y-intercept
  - R --- The correlation coefficient (how close to a straight line it is)
- 8- If the value for R is 1.00 or not less than 0.98, the graph is statistically a good straight line. This indicates that the acceleration is constant. Record the slope of the graph, the acceleration. Its units are in meter/sec<sup>2</sup>. Study the graph as long as you wish, and when finished, press <RETURN>. Press <ESC> until you move to the main menu to make another run.
- 9- Change the applied force (due to m<sub>w</sub>) by moving masses from the cart to the hanger. This changes the force without changing the total mass. Record your new values in the data table. Repeat steps 3-8 at least five times using different values for m<sub>w</sub>.
- 10- Now change the total mass, yet keep the net force the same as in one of your first five runs. Add mass to the cart, keeping the hanging mass the same. Record your new mass values, and the accelerations that you obtain. Repeat at least five times.

#### 4. DISCUSSIONS AND CONCLUSIONS

1. Calculate the net force acting on the cart for each trial that you performed. The net force is the tension in the string (if friction is neglected), which can be calculated as:
 
$$F_{\text{net}} = (m_w m_c) / (m_c + m_w)$$
2. Also calculate the total mass that was accelerated in each trial: (m<sub>c</sub>+m<sub>w</sub>).
3. Graph the acceleration versus the applied force for cases having the same total mass. Graph the acceleration versus total mass for cases with the same applied force. What relationships exist between the graphed variables?
4. Calculated the theoretical acceleration using Newton’s 2<sup>nd</sup> Law: F<sub>net</sub>=ma. Compare the actual acceleration with the theoretical acceleration, determining the percentage difference between the two.
5. Discuss your results. In this experiment, you measured only the average acceleration of the object between the two photogates. Do you have reason to believe that your results



also hold true for the instantaneous acceleration? Explain. What further experiments might help extend your results to include instantaneous acceleration?

## 5. QUESTIONS

1. Analyze the sources of error in the performance of the experiment.
2. If a loaded elevator weighs 3 tons, what force of tension in the hoisting cable (N) will be required to move it upward at a uniform rate of  $6 \text{ m/s}^2$ ?
3. According to Newton's laws, an external force is needed to stop a car when brakes are applied. Where is this force and what is its origin?
4. A person on an upward-moving elevator is throwing darts at a target on the elevator wall. How should she aim the dart if the elevator has (a) constant velocity, (b) constant upward acceleration, (c) constant downward acceleration.
5. When a moving car is slowed to a stop with its brakes, what is the direction of its acceleration vector? Describe the path of a ball dropped by a passenger during the time the car is slowing down.
6. A horizontal force acts on a mass that is free to move. Can it produce an acceleration if the force is less than the weight of that mass.

**Table 7.1:** Acceleration of a laboratory cart

Trial #	$m_c$	$m_w$	Experiment Acceleration	Applied Force	Total mass	Theory Acceleration	%Difference
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							



**GENERAL PHYSICS  
PART A: MECHANICS  
EXPERIMENT – 8**

**THE INCLINED PLANE AND SLIDING FRICTION**

**1. PURPOSE**

To study the relationship between force, mass and angle and compare the mathematical solution with data taken directly from a scale model and to investigate some of the properties of sliding friction-the force that resists the sliding motion of two objects when they are already in motion

**2. THEORY**

Force is the cause of motion. Inertia is that property of mass which resists a change in motion. Newton's first law of motion states that a body at rest or in motion will continue at rest or in motion at the same speed and in the same direction, unless acted upon by an unbalanced force. When a force acts on a body (Newton's second law), the change in motion produced (i.e., acceleration) is produced to the force acting and inversely proportional to the mass of the body. This law may be stated as

$$\vec{a} = \frac{\vec{F}}{m} \quad (8.1)$$

this equation may be written as

$$\vec{F} = m\vec{a} \quad (8.2)$$

which is the mathematical statement of Newton's second law. One important example of Newton's second law is the expression for an object's weight. The weight of an object on earth is the gravitational force exerted on it by the earth. As a result, we know that near the earth's surface, when we neglect air resistance, the acceleration is the same for all falling bodies. This constant acceleration is known as the acceleration of gravity,  $g$ , and has the standard value  $9.807 \text{ m/s}^2$ . When an object is dropped near the earth's surface, it is accelerated by the gravitational force (equal to its weight) with an acceleration  $g$ . Thus, by Newton's second law, the weight  $w$  becomes

$$W = mg \quad (8.3)$$

We see in this expression the relation between mass and weight: Weight is a force proportional to the mass of a body and  $g$  is the constant of proportionality.

When an object such as brick rests on the ground, the gravitational force continues to act on the brick, even though it is not accelerating. According to Newton's second law, the net force on the brick at rest must be zero. There must be another force acting on the brick that opposes the gravitational force. This force is provided by the ground (Fig.8.1a). The force provided by the ground is perpendicular to the surface of contact and is known as the **normal force**. If the brick rests on an inclined surface, the gravitational force  $\mathbf{mg}$  acting on the brick is still directed downward. The normal force  $\mathbf{N}$  acts perpendicular to the surface, and since the surface is inclined, the normal force must be inclined (Fig.8.1b). That is, it is the vector sum of  $\mathbf{mg}$  and  $\mathbf{N}$ . The brick will then accelerate down the incline at a rate determined by this net force and the brick's mass.

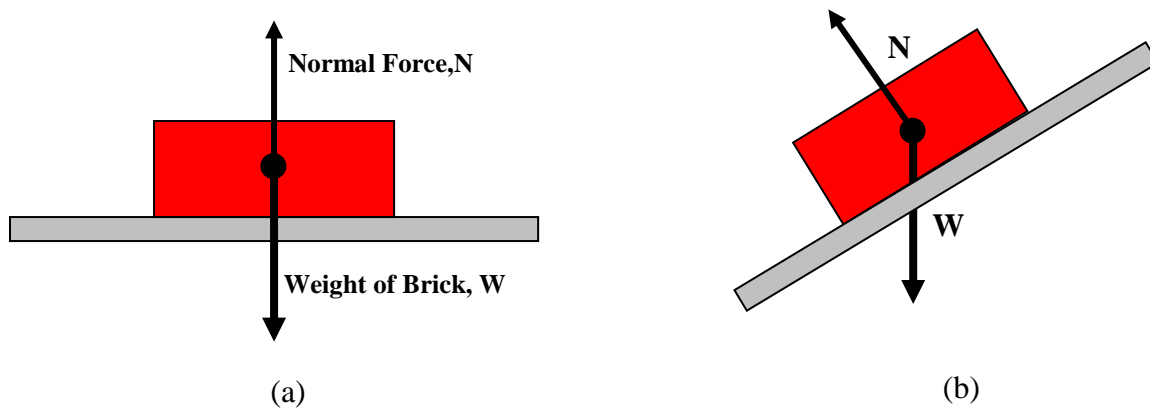


Figure 8.1: The normal force is always perpendicular to the contact surface (a) The normal force is equal to the weight of the brick. (b) The normal force is less than the weight of the brick.

The surface of any material, no matter how smooth it may seem to the touch, is actually full of irregularities which oppose the sliding of any other body across it. This force of opposition as one surface slides across another is called friction. Friction is a force which always acts to oppose a change in motion.

Since friction is a reaction force, it follows from Newton's third law that when there is no force tending to cause a relative motion between two surfaces, there is no force of friction. As shown in Fig.8.2, let A and B be two bodies, and let  $\vec{F}$  be a force which tends to cause A slide across B. Let  $N$  be the normal force pressing the two bodies together. (In this case  $N$  equals the weight of body A.) Note that  $F_f$ , the force of friction, acts at the boundary between the two surface and is opposite in direction to  $F$ .

If  $\vec{F}$  is zero,  $\vec{F}_f$  is zero. As  $F$  is increased,  $\vec{F}_f$  increases also, until the condition is reached where motion impends. At this instant, just as the block A would begin to slide, the

force of friction reaches its maximum value is said to be the force of limiting friction or the force of static friction  $\vec{F}_f$ .

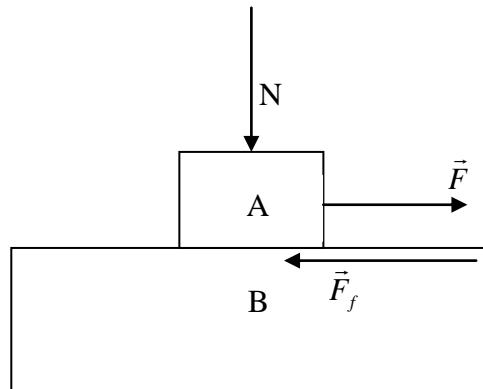


Figure 8.2: Diagram showing the factors involved in sliding friction

Once the body A begins to move, it will be found that the force of friction diminishes somewhat. This lowered value of frictional force for surfaces where sliding already exists, is called the force of kinetic friction  $\vec{F}_k$ .

For elementary studies of friction in the laboratory, the following statements are nearly, if not quite exactly, true for dry surfaces.

1. The force of kinetic friction is almost independent of the area of contact, but is directly related to the force pressing the two surfaces together- the normal force.
2. The force of kinetic friction depends on the nature of the surfaces. This constant of the sliding surfaces is called the coefficient of friction.
3. The force of kinetic friction is almost independent of the relative velocity of the sliding surface for normal velocity ranges.

Thus, the coefficient of kinetic friction is defined as

$$\mu_k = \text{force of kinetic friction} / \text{normal force}$$

or

$$\mu_k = F_k/N \tag{8.4}$$

### 3. EXPERIMENTAL PROCEDURE

#### Part A: Inclined Plane

1. Weigh the rolling mass on the spring balance and record its mass (M) and weight(W).
2. Now set up the equipment as shown in Fig. 8.3. Calculate the force that must be exerted by the string and by the ramp, W can be resolved into two components;  $W_x$ , a component

directed along the surface of the ramp, and  $W_y$ , a component perpendicular to the surface of the ramp. The magnitudes of  $W_x$  and  $W_y$  are easily calculated:  $W_x = W \sin \theta$ , and  $W_y = W \cos \theta$ .  $F_x$ , the force provided by the string, must be equal and opposite to  $W_x$ .  $F_y$ , the force provided by the ramp, must be equal and opposite to  $W_y$ .

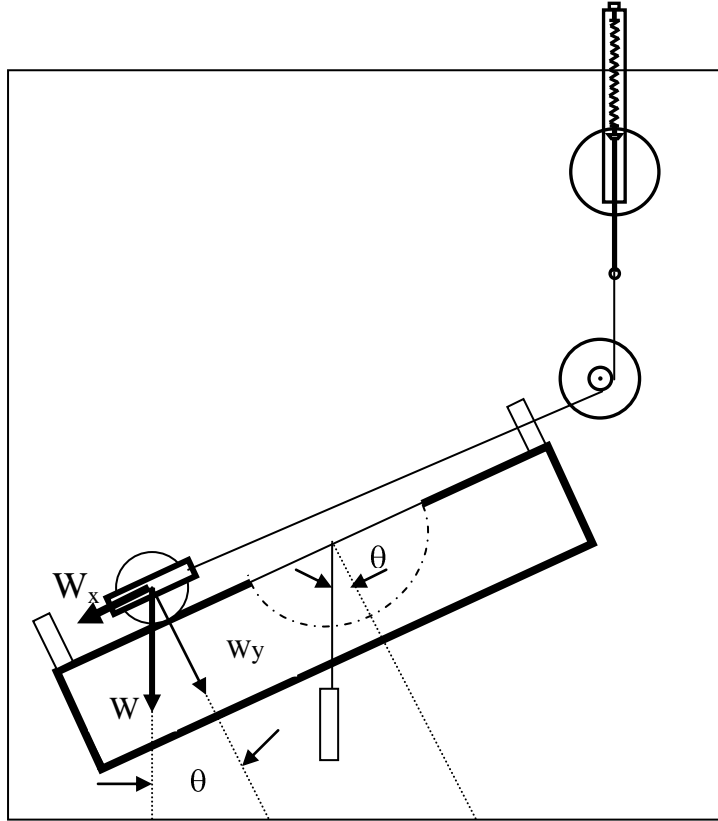


Figure 8.3: Equipment Setup

- 3- Adjust the angle of inclination of the ramp to each of the values shown in Table 8.1, below. At each value, record the experimental value of  $F_x$ , as read on the Newton scale of the spring balance, in Table 8.1. For accurate results, the string must be parallel to the surface of the inclined plane.
- 4- To measure the force of the rolling mass on the inclined plane, set up the equipment as shown in Fig.8.4. Vary the tilt of the inclined plane until the hanging mass and the rolling mass are in equilibrium.
- 5- Record the mass ( $M'$ ) and weight ( $W'$ ) of the hanging mass, and the angle of inclination ( $\theta$ ) of the inclined plane.
- 6- Set up the spring balance and a pulley as shown in Fig.8.5. Adjust the pulley and the spring balance so the string pulls the bracket of the rolling mass at a  $90^\circ$  angle to the

surface of the inclined plane. Pull the spring balance up until the force just barely lifts the rolling mass off the inclined plane.

7- Read the value of  $F_y$  on the Newton scale of the spring balance.

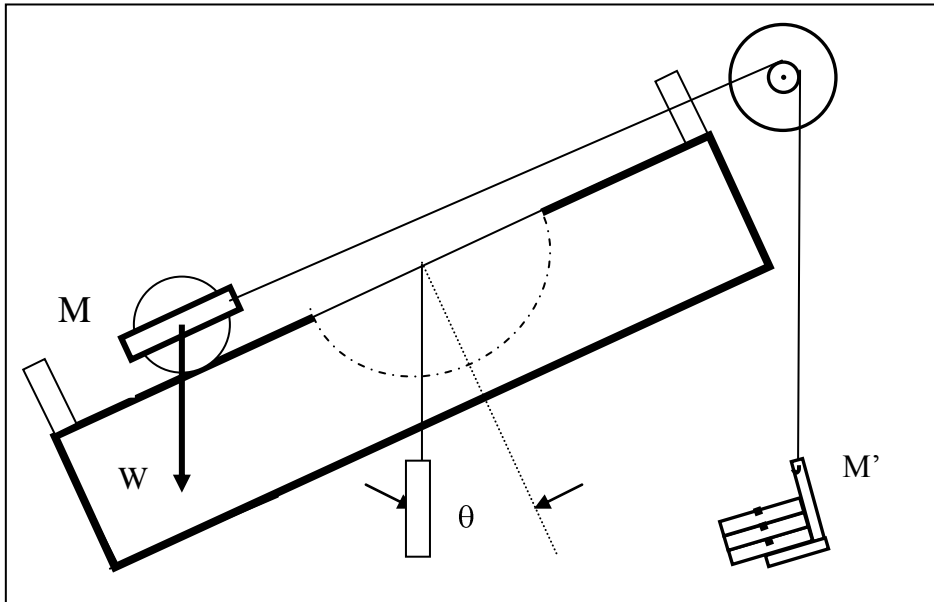


Figure 8.4: Normal Force, Equipment Setup

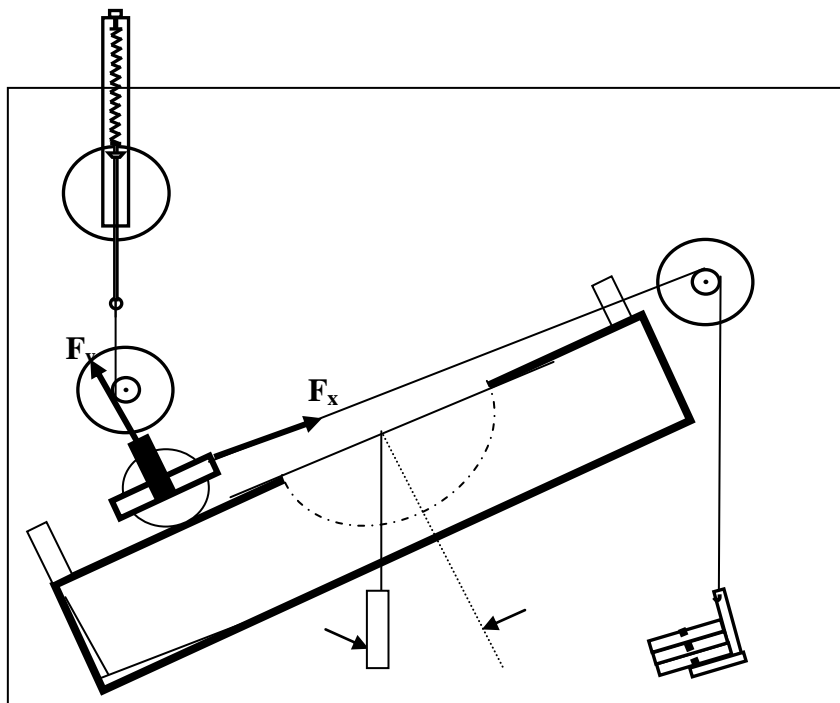


Figure 8.5: Measuring the Normal Force

## Part B: Sliding Friction

- 1- Use the spring scale to determine  $W$ , the magnitude of the weight of the friction block.
- 2- Set up the equipment as shown in Fig.8.6. Use the built-in plumb bob to ensure that the inclined plane is level.

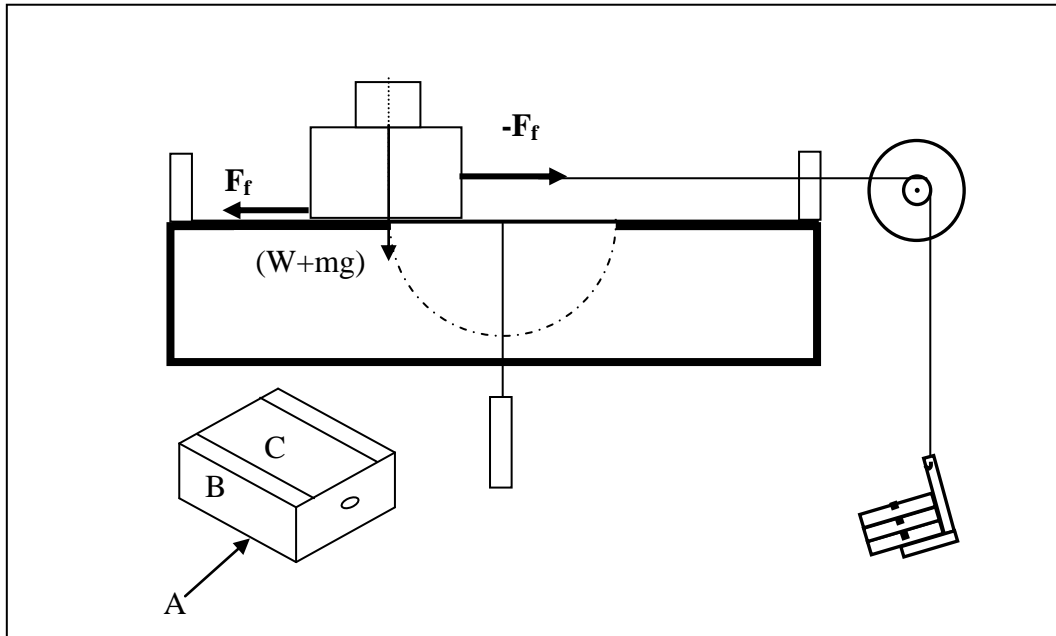


Figure 8.6: Equipment Setup

3. Adjust the position of the pulley so that the string is level with the surface of the inclined plane. Adjust the mass on the mass hanger until, when you give the friction block a small push to start it moving, it continues to move along the inclined plane at a very slow, constant speed. If the block stops, the hanging mass is too light; if it accelerates, the mass is too large. The weight of the hanging mass that is just sufficient to provide a constant slow speed is  $F_f$ , the force of the sliding friction of the friction block against the inclined plane.

Three variables can be varied while measuring  $F_f$ .

They are:

**Normal force ( $W+mg$ )** – Place masses of weight  $W$  on top of the friction block to adjust the normal force between the block and the inclined plane.

**Contact Material** – Using sides A and B of the friction block, wood is the material in contact with the inclined plane. Using side C, only the two strips of Teflon tape contact the inclined plane.



**Contact Area (A, B, C)** – Adjust the area of contact between the friction block by having side A, B, or C of the friction block in contact with the inclined plane. (Note: Using side C, the contact area is the surface area of the two strips of Teflon tape.)

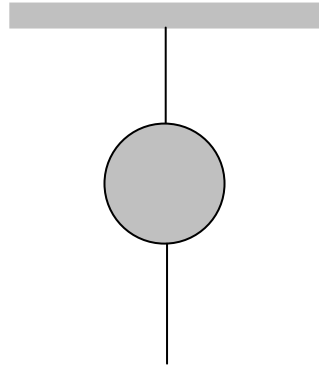
#### 4. DISCUSSIONS AND CONCLUSIONS

- 1- For each angle of inclination, calculate  $W_x$ , the magnitude of the x-component of  $W$ , using the formula shown in Table 8.1, then calculate the percent difference between  $W_x$  and the measured value of  $F_x$ .
- 2- Does the vector model of the forces accurately predict your measured results?
- 3- Calculate  $F_x$ , the component of the weight of the rolling mass parallel with the inclined plane ( $F_x = W \cos \theta$ ).
- 4- Does  $F_x = W$ ?
- 5- Calculate  $W_y$ , the magnitude of the y-component of the weight of the rolling mass.  
 $W_y = W \sin \theta$
- 6- Does the vector model of forces accurately predict the force exerted by the rolling mass on the inclined plane?
- 7- At each value of  $M$ , adjust the hanging mass to determine the value of  $F_f$ . Perform this measurement using side A, B, and C of the friction block. For each measurement, calculate the ratio between the magnitude of the sliding friction ( $F_f$ ) and the magnitude of the normal force ( $W + Mg$ ) and record on Table 8.2.
- 8- Does the value of sliding friction between two objects depend on the normal force between the two objects? If so, what is the relationship between normal force and sliding friction?
- 9- Does the value of sliding friction between two objects depend on the area of contact between the two objects? If so, what is the relationship between area of contact and sliding friction?
- 10- Does the value of sliding friction between two objects depend on the materials that are in contact?
- 11- Combining the results of this experiment and Experiment 8, what would be the value of  $F_f$  for the friction block (with no additional masses on top) if the inclined plane were at an angle of  $45^\circ$  and side A was in contact with the inclined plane?

#### 5. QUESTIONS

1. Analyze the sources of error in the performance of the experiment.
2. Explain the difference between uniform motion and uniformly accelerated motion.
3. A book rests motionless on a table. Does that mean there are no forces acting upon it?

4. A child sits in a swing that is not moving. Describe all forces present and identify all action-reaction pairs.
5. Suspend a heavy weight from a light string and attach a similar below it as shown in figure. If you pull on the lower string with steadily increasing force, the upper string will break; if you pull the lower string with a jerk, the lower string will break. Explain both cases.



6. Describe the difference between mass and weight?
7. Explain, the effect of very high relative velocity of the sliding surface on the force of kinetic friction.
8. Why is it necessary that the block be moving with uniform velocity, in determining the force of kinetic friction?
9. Will a speeding automobile stop more quickly with the wheels locked (tires skidding) or with the wheels braked just to the point of impending skidding? Why?
10. There is a limit beyond which further polishing of a surface increases rather than decreases frictional resistance. Can you explain this?

<b>Table 8.1: Measurement data</b>			
Angle of Inclined plane	$F_x$ (Measured)	$W_x = W \sin \theta$ (Calculated)	$(F_x - W_x) / (1/2)(F_x + W_x) \times 100\%$ (Percentage Difference)
15°			
30°			
45°			
60°			
75°			

<b>Table 8.2: Measurement data</b>							
M (g)	W + Mg (n)	$F_f$ (n)			$F_f(W + Mg)$		
		A	B	C	A	B	C
0							
50							
100							
150							
200							
250							



**GENERAL PHYSICS  
PART A: MECHANICS  
EXPERIMENT – 9  
THE CONSERVATION OF ENERGY**

### **1. PURPOSE**

To investigate the initial gravitational potential energy of the cart are converted to thermal and kinetic energy as the cart slides to a stop and the thermal energy generated on the surfaces is the same as the work done against sliding friction.

### **2. THEORY**

A body in motion possesses energy associated with its motion because it can do work upon impact with another object. This energy of motion is called kinetic energy. In applying a force to the particle, we performed an amount of work  $Q = \max$ . The effect of the work done on the particle has been to change its motion. The quantity  $\frac{1}{2}mv^2$  is given the name kinetic energy (KE). More specifically, this equation is called the translational kinetic energy. A particle of mass  $m$  moving with a speed  $v$  possesses a kinetic energy due to its translational motion that is given by

$$KE = \frac{1}{2}mv^2 \quad (9.1)$$

The SI units for kinetic energy are  $\text{kg}\cdot\text{m}^2/\text{s}^2$  or joules, the same as the units for work. We have seen that an object in motion has kinetic energy. Objects may also have energy in other forms. When a spring is stretched, it acquires energy called potential energy. The term potential energy does not mean that the energy is not real energy. Rather, it means that the energy is stored and is available to be converted into work or some other form of energy.

Gravitational potential energy is one of the most familiar forms of potential energy. A mass  $m$  initially at rest on the ground. It is then lifted slowly at a uniform velocity with a constant upward force just strong enough to equal the downward force of gravity  $mg$ . If the log is raised from the ground to a height  $h$ , the work done on the log is the net lifting force times the distance travels, or

$$W = Fh = mgh \quad (9.2)$$

If the log is released, it will fall. As it falls it accelerates, gaining velocity and kinetic energy, and thereby the ability to do work. Because the log at height  $h$  is capable of doing work if it is released, we say it has potential energy due to its position. More specifically, we say in this

case that it has gravitational potential energy. Thus, near the earth's surface an object's gravitational potential energy with respect to some reference level is

$$PE = mgh \quad (9.3)$$

where  $h$  is the height above the reference level. Again, the units are joules. The sum of the body's kinetic energy and potential energy is its total mechanical energy. If the forces are all conservative, the sum of the kinetic and potential energies is a constant. This statement is the law of conservative of energy, which can be written as

$$KE_2 + PE_2 = KE_1 + PE_1 \quad (9.4)$$

Sometimes this last equation is useful way to state the law of conservative of mechanical energy.

The presence of a frictional ( or other non conservative) force, mechanical energy is nor conserved. Friction is a non conservative force. The direction of the frictional force acts to retard the motion. Therefore the work done by friction is negative. In that case, the final mechanical energy is less than the initial mechanical energy. Then we can write,

$$E_{\text{final}} - E_{\text{initial}} = W_{\text{friction}} \quad (9.5)$$

where  $W_{\text{friction}}$  is the product of the frictional force  $F_f$  with the distance  $d$  through which it acts.

Using the principle of conservation of energy, we can equate the initial energy of the system with the final (i.e. thermal) energy of the system. This leads to

$$mgD\sin\theta = \mu_k mgD\cos\theta + \frac{1}{2} mv^2 \quad (9.6)$$

$$(\text{Gravitational P.E.}) = (\text{work done against friction} + \text{Kinetic E.})$$

where  $m$  is the mass of the cart plus the friction block,  $D$  is the distance that block slides after the cart's plunger is released,  $\theta$  is the angle of the ramp to the horizontal, and  $\mu_k$  is the coefficient of kinetic or "sliding" friction.

If the angle of the ramp is high enough, the friction block will down the ramp with uniform acceleration due to a net force on the block. The net force on the block is the difference between the component of the gravitational force ( $mg\sin\theta$ ) that is parallel to the surface of the ramp and the friction force ( $-\mu_k mg\cos\theta$ ) that retards the motion. The angle  $\theta$  is the angle of the ramp when the block slides down the ramp with uniform acceleration. The acceleration down the ramp is given by:

$$a = (m_2 g \sin \theta - m_1 g - m_2 g \mu_k \cos \theta) / (m_1 + m_2) \quad (9.7)$$

### 3. EXPERIMENTAL PROCEDURE

- 1- Place the cart with the friction block on the ramp. Set up the ramp (see Fig. 9.1) at a relatively low angle (one that does not cause the friction block to begin sliding down the ramp by itself).

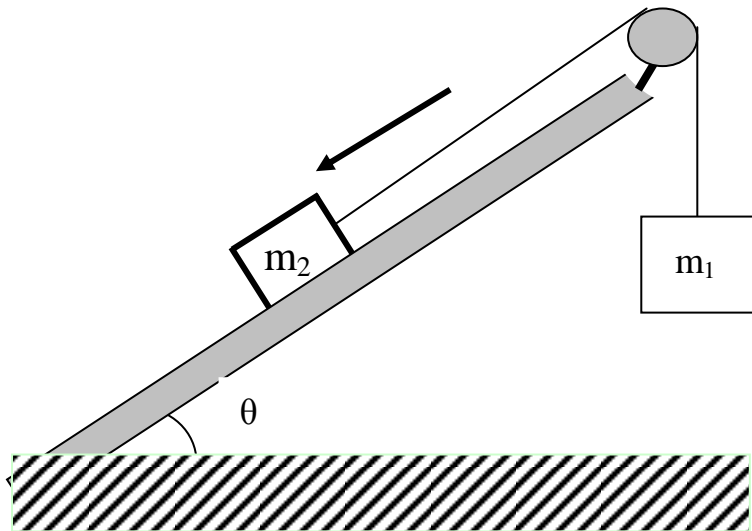


Figure 9.1: Equipment Setup

- 2- When you have gotten to the main menu, select option  $\langle M \rangle$ , the motion timer. In this mode, the computer will measure and record up to 200 time intervals as your pulley spins.
- 3- Now press  $\langle \text{RETURN} \rangle$  on the computer. Release the mass hanger which fall downward, pulling the cart across the table. Stop the timing just before the mass hanger reaches the floor by pressing  $\langle \text{RETURN} \rangle$ .
- 4- When the computer finishes its calculations, it will display the measured times. Press the space bar on the keyboard to scroll through the data. When you reach the bottom of the ramp, press  $\langle \text{RETURN} \rangle$  to move to the next menu.
- 5- At the next menu, choose option  $\langle G \rangle$  to enter the graphing mode, then choose  $\langle A \rangle$  to tell the computer you are using the Smart Pulley to monitor a linear motion. When you get to the graphing menu, choose  $\langle D \rangle$  to select a distance-time graph.
- 6- In the next menu, choose  $\langle G \rangle$ , then press the space bar so your graph will have a grid. Also press  $\langle P \rangle$  followed by  $\langle \text{SPACE BAR} \rangle$  so your graph will not have point protectors. Pressing  $\langle \text{RETURN} \rangle$  starts the actual graphing routine.

- 7- Examine the graph, then press <RETURN>. You will be shown a new menu. If your graph shows reasonably constant speed, press <T> to see the data.
- 8- Now choose option <A> from the same menu, so you can alter the style of the graph. Choose a velocity-time graph by pushing <V> to display the velocity and time information. Record the first 25 velocities in your data table.
- 9- Place the cart with the friction block on the ramp. Set up the ramp (see Fig. 9.2) at a relatively low angle (one that does not cause the friction block to begin sliding down the ramp by itself).
- 10- Experiment repeat different angle (at least 5 times) and different mass  $m$  (at least 3 times). And repeat step 9.

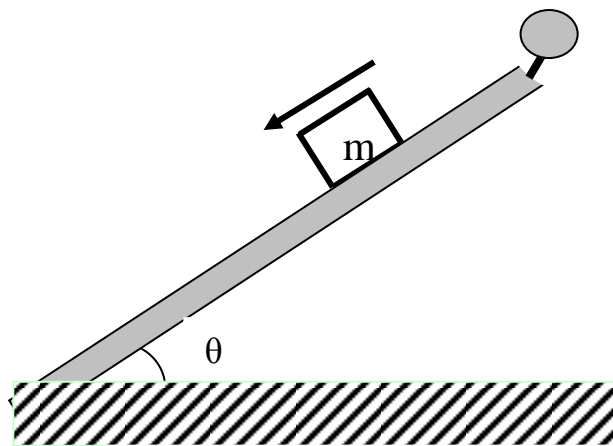


Figure 9.2: Equipment Setup

#### 4. DISCUSSION AND CONCLUSION

- 1- In your write-up include a description of the motion, a description of the graphs that you obtained, and try to generalize on what the different shapes of graphs mean of the motion they describe.
- 2- Compare your results with your prediction. Compute the percent difference between these two values.
- 3- Determine the average value of acceleration and use Equ. 9.7 to calculate the coefficient of kinetic or “sliding” friction.
- 4- Use the Equ. 9.6, determine the  $v$  velocity of the cart and also verify the conservation energy of the cart.

#### 5. QUESTIONS

- 1- In analyzing this system, has the energy been fully accounted for? Discuss.
- 2- How do your results agree with your prediction? Discuss.



- 3- What if you launched the cart up the same ramp? How far up would it go?
- 4- When the mass of the cart was doubled, why did the gravitational potential energy remain about the same
- 5- Is the work done by frictional forces always negative? If not, give an example.
- 6- Does kinetic energy depend on the direction of the motion involved? Can it be negative?
- 7- An automobile of mass  $m$  and speed  $v$  is moving along a highway. The driver jams on the brakes and the car skids to a halt. In what form does the lost kinetic energy of the car appear?
- 8- An object is dropped and observed to bounce to one and one-half times its original height. What conclusions can you draw from these observations?
- 9- What happens to the potential energy an elevator loses in coming down from the top of a building to a stop at the ground floor?



**GENERAL PHYSICS**  
**PART A: MECHANICS**  
**EXPERIMENT – 10**  
**COLLISIONS (CONSERVATION OF MOMENTUM)**

**1. PURPOSE**

In this experiment, you will use the Smart Pulley to investigate momentum conservation in inelastic collisions, conservation of energy and momentum in elastic collisions. The colliding objects will be a pair of lab carts with Velcro fasteners. Once the carts collide, they stick together, so the collisions are inelastic and elastic.

**2. THEORY**

**Elastic Collision:** An elastic collision is one in which kinetic energy and momentum are both conserved. A close approximation of such an elastic collision is provided when two pucks, both of which are initially in motion on a frictionless surface collide.

Before collision of the two carts, the situation can be represented as follows:

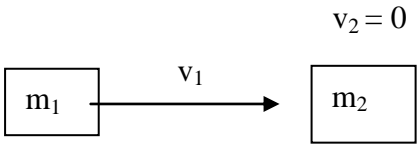


Figure 10.1: Before the an elastic collision

where  $m_1$  = the mass of the first cart,  $v_1$  = the velocity of the first cart,  $m_2$  = the mass of the second cart, and  $v_2$  = the velocity of the second cart, which is zero.

During an elastic collision, the kinetic energy is converted to potential energy and back into kinetic energy as the carts bounce off one another. After the collision, the carts accelerate away from each other, or all the kinetic energy of one cart is transferred to the other cart, which accelerates away from the first cart, has a velocity of zero. When acceleration reaches 0, the situation can be as represented below:



Figure 10.2: After the an elastic collision

The momentum of the system at any point in time is expressed as follows:

$$P = m_1v_1 + m_2v_2 \quad (10.1)$$

Where  $m_1v_1$  are the mass and velocity of the first cart and  $m_2v_2$  are the mass and velocity of the second cart. Since the momentum is conserved after the collision, the following relationship exists:

$$m_1v_1 + m_2v_2 = m_1v_{1\text{after}} + m_2v_{2\text{after}} \quad (10.2)$$

The total kinetic energy (KE) of the system at any moment in time is represented by:

$$KE = \frac{1}{2} m_1v_1^2 + \frac{1}{2} m_2v_2^2 \quad (10.3)$$

After the elastic collision, the kinetic energy and momentum are conserved:

$$\frac{1}{2} m_1v_1^2 + \frac{1}{2} m_2v_2^2 = \frac{1}{2} m_1v_{1\text{after}}^2 + \frac{1}{2} m_2v_{2\text{after}}^2 \quad (10.4)$$

**Inelastic Collision:** If a collision is inelastic then, by definition, the kinetic energy is not conserved. The final kinetic energy may be less than the initial value, the difference being ultimately converted to heat energy or to potential energy of deformation in the collision. In any case the conservation of momentum still holds, as does the conservation of total energy. Before collision of the two carts, the situation can be represented as follows:

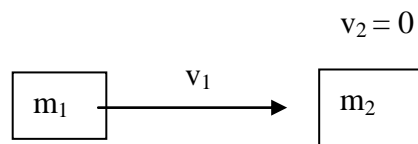


Figure 10.3: Before the inelastic collision

where  $m_1$  = the mass of the first cart,  $v_1$  = the velocity of the first cart,  $m_2$  = the mass of the second cart, and  $v_2$  = the velocity of the second cart, which is zero.

After the collision, the carts stick together and move as one mass, as represented below:

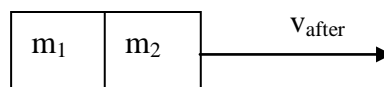


Figure 10.4: After the inelastic collision

The momentum of the system at any point in time is expressed as follows:

$$P = m_1v_1 + m_2v_2 \quad (10.5)$$

where  $m_1v_1$  are the mass and velocity of the first cart and  $m_2v_2$  are the mass and velocity of the second cart. Since the momentum is conserved after the collision, the following relationship exists:

$$m_1v_1 + m_2v_2 = m_{\text{after}}v_{\text{after}} \quad (10.6)$$

where  $m_{\text{after}}$  is the mass of the carts and  $v_{\text{after}}$  is the velocity of the two carts stick together. The total kinetic energy (KE) of the system at any moment in time is represented by:

$$KE = \frac{1}{2} m_1v_1^2 + \frac{1}{2} m_2v_2^2 \quad (10.7)$$

In contrast to the case with momentum, KE is not conserved after the collision:

$$\frac{1}{2} m_1v_1^2 + \frac{1}{2} m_2v_2^2 \neq \frac{1}{2} m_{\text{after}}v_{\text{after}}^2 + \frac{1}{2} m_{\text{after}}v_{\text{after}}^2 \quad (10.8)$$

### 3. EXPERIMENTAL PROCEDURE

#### Part A-) Inelastic Collision

- 1- Set up the apparatus as shown in Fig.10.5. In order to create an elastic collision, put a piece of Velcro fastener on the front side of cart #1 and a piece of the opposite type of Velcro on the back of cart #2. Attach a piece of thread to cart #1. The thread should be about 10 cm longer than the distance from the cart to the floor. Connect the Smart Pulley to your computer, and make sure the proper connections have been made before going on.

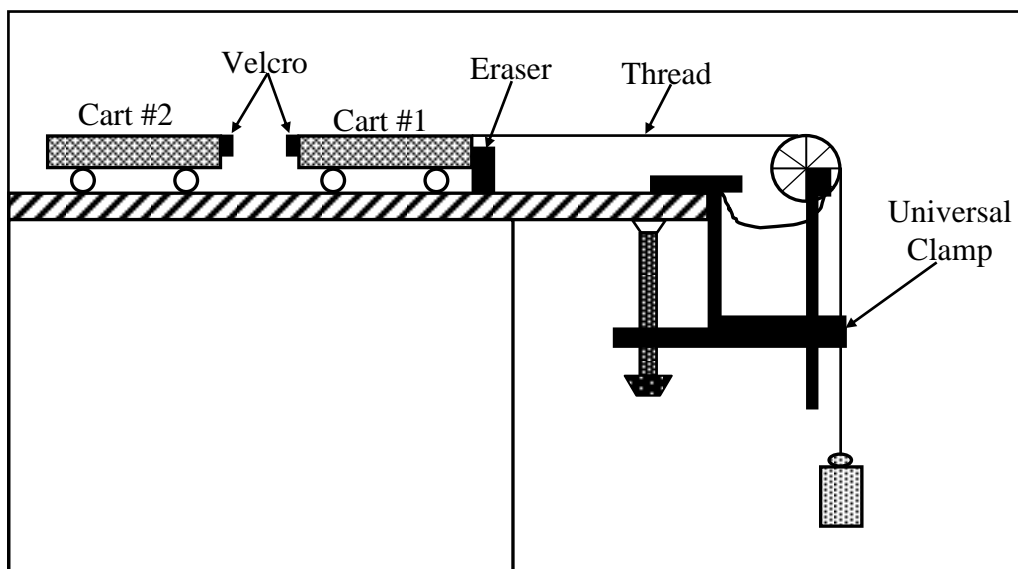


Figure 10.5: Equipment setup for inelastic collision

- 2- Insert the Smart Pulley software disk into your computer disk drive and start up the computer.
- 3- Determine the mass of each of your lab carts. Record these as  $m_1$  and  $m_2$ , respectively, in Table 10.2. Fasten the thread running from cart #1 to the mass hanger by wrapping 4-5 turns of thread around the notched area of the hanger. The purpose of the mass hanger is to keep a small amount of tension on the thread to turn the pulley as the cart moves.
- 4- Move cart #1 until the mass hanger almost touches the floor. With the cart motionless and the holes in the pulley positioned so that the LED on the photogate is off, select <M> on the main menu.
- 5- Give cart #1 a push so that it collides with cart #2 near the center of the table. Continue timing until the thread runs out, then press <RETURN> to halt the timing process.
- 6- When the computer finishes processing the times, move to the graphing function. Select <A> to tell the computer that you are using the Smart Pulley to monitor a linear motion. Next choose <V> which will give you a velocity-time graph.
- 7- When finished looking at the graph, press <RETURN>. Choose <T> to display a table of the velocity-time data. Copy the data Table 1 (you need only be concerned with the data for timing intervals before the collision and 5 intervals after the collision).
- 8- Change the relationship between  $m_1$  and  $m_2$  by adding mass to either of the two carts. Repeat steps 3-7 five times with different mass combinations.

### **Part B-) Elastic Collision**

- 1- Set up the apparatus as shown in Fig.10.6. In order to create an elastic collision, attach a piece of thread to cart #1. The thread should be about 10 cm longer than the distance from the cart to the floor. Connect the Smart Pulley to your computer, and make sure the proper connections have been made before going on.
- 2- Insert the Smart Pulley software disk into your disk drive and start up the computer.
- 3- Determine the mass of each of your lab carts. Record these as  $m_1$  and  $m_2$ , respectively, in Table 10.2. Fasten the thread running from cart #1 to the mass hanger by wrapping 4-5 turns of thread around the notched area of the hanger. The purpose of the mass hanger is to keep a small amount of tension on the thread to turn the pulley as the cart moves.
- 4- Move cart #1 until the mass hanger almost touches the floor. With the cart motionless and the holes in the pulley positioned so that the LED on the photogate is off, select <M> on the main menu.
- 5- Give cart #1 a push so that it collides with cart #2 near the center of the table. Continue timing until the thread runs out, then press <RETURN> to halt the timing process.

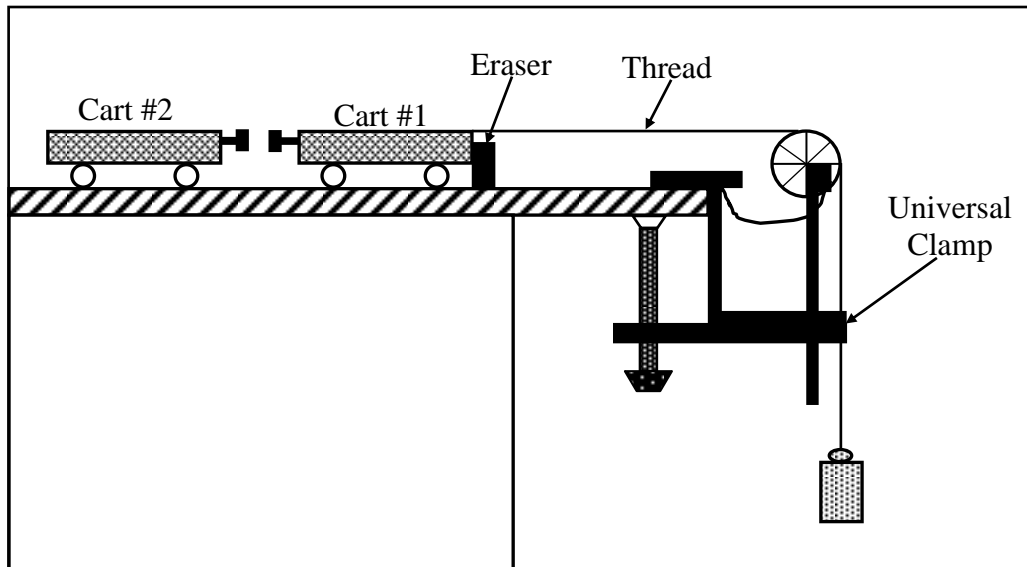


Figure 10.6: Equipment setup for elastic collision

- 6- When the computer finishes processing the times, move to the graphing function. Select <A> to tell the computer that you are using the Smart Pulley to monitor a linear motion. Next choose <V> which will give you a velocity-time graph.
- 7- When finished looking at the graph, press <RETURN>. Choose <T> to display a table of the velocity-time data. Copy the data Table 10.1 (you need only be concerned with the data for timing intervals before the collision and 5 intervals after the collision).
- 8- Change the relationship between  $m_1$  and  $m_2$  by adding mass to either of the two carts. Repeat steps 11-15 five times with different mass combinations.

#### 4. DISCUSSIONS AND CONCLUSIONS

##### For Inelastic Collision:

1. Calculate the momentum of cart #1 immediately before the collision, and the momentum of the combined masses immediately after the collision for each of your trials.
2. Determine the percentage difference between the pre- and post-collision momentum for each trial.

##### For Elastic Collision:

3. Calculate the momentum of cart #1 immediately before the collision, and the momentum of the combined masses immediately after the collision for each of your trial.
4. Determine the percentage difference between the pre- and post-collision momentum and energy for each trial.

#### 5. QUESTIONS

- 1- List the sources of error effecting the values of initial and final velocities.
- 2- What is the percentage error of the value of  $v_{2f}$  ?
- 3- In the elastic collision was  $K_i=K_f$  ? If not, what are the possible reasons for this difference?  
Can you justify this difference by the errors due to the instrument?
- 4- Are  $v_i$  and  $v_f$  equal in magnitude and direction in elastic collision ? Is the momentum conserved? Is the energy conserved ?
- 5- Compare the values of  $K_i$  and  $K_f$  and explain the difference ?
- 6- How did the inelastic collision effect the total momentum and total kinetic energy in the system ?
- 7- How did the elastic collision effect the total momentum and total kinetic energy in the system ?
- 8- What effect did friction have on the momentum and kinetic energy of the system for inelastic and elastic collision ?
- 9- What are other possible contributors to the variation of the experimental data from the expected (theoretical) values for inelastic and elastic collision ?
- 10- Two clay balls of equal mass and speed strike each other head-on, stick together, and come to rest. Kinetic energy is certainly not conserved. What happened to it? Is momentum conserved ?
- 11- Consider a one dimensional elastic collision between a given incoming body A and a body B initially at rest. How would you choose the mass of B, in comparison to the mass of A, in order that B should recoil with (a) the greatest speed, (b) the greatest momentum and (c) the greatest kinetic energy ?



<b>Table 10.1: Velocities of Carts</b>									
Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
Before	After	Before	After	Before	After	Before	After	Before	After

<b>Table 10.2: Momenta and Energy of Carts</b>								
Trial	$M_1$	$M_2$	Initial Velocity	Initial Momentum	Initial Energy	Final Velocity	Final Momentum	Final Energy



**GENERAL PHYSICS  
PART A: MECHANICS  
EXPERIMENT – 11**

**ENERGY ON AN INCLINED PLANE**

**1. PURPOSE**

The purpose of this experiment is to show the conservation of mechanical energies of rolling object on an inclined plane.

**2. THEORY**

An object at the top of an inclined plane has gravitational potential energy (GPE). Moving down the inclined, it accelerates, and this GPE is converted into kinetic energy (KE). If friction is small, the conversion is nearly complete. However, if object is a rolling ball, the kinetic energy shows up in two forms: translational kinetic energy and rotational kinetic energy. Both types of energy must be considered in determining whether mechanical energy is conserved.

Fig. 11.1 shows a disk of mass  $m$  and radius  $r$  at the top of inclined plane. The axis of the disk is parallel to the edge of the plane so that the disk, when released, rolls straight down the plane. If the frictional force is great enough, there is no sliding and the disk rolls without slipping. The thickness of the disk is not important here, except that for a given material and radius, the total mass of the disk depends upon its thickness.

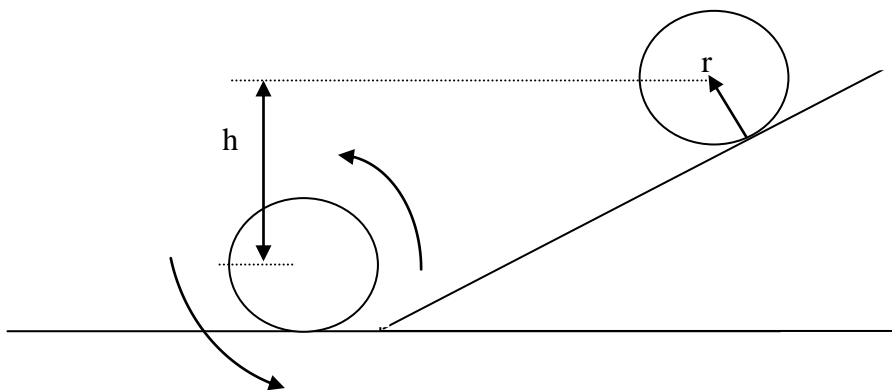


Figure 11.1: A disk rolling down an inclined plane. Its potential energy at the top is transformed into translational and rotational kinetic energy at the bottom.

At the top of the plane the disk has a potential energy relative to its position at the bottom. Here  $h$  is the vertical distance through which the center of mass moves from the top to the bottom of the plane. If the disk rolls down to the bottom of the plane without slipping,

the n all of the initial potential energy is completely transformed into kinetic energies of rotation and translation at the bottom. Because the disk rolls without slipping, we can neglect energy loss due to friction. Then we may extend the idea of conservation of mechanical energy to include rotational as well as translational kinetic energy. Consequently,

$$\Delta PE + \Delta KE_{\text{trans}} + \Delta KE_{\text{rot}} = 0 \quad (11.1)$$

here  $KE_{\text{trans}}$  is the kinetic energy due to translation of the center of mass of the disk and  $KE_{\text{rot}}$  is the kinetic energy of rotation about its center of mass. The sum of these two terms is the total kinetic energy of the rolling disk:

$$KE_{\text{tot}} = KE_{\text{trans}} + KE_{\text{rot}} = \frac{1}{2} mv^2 + \frac{1}{2} I\omega^2 \quad (11.2)$$

We see that the magnitude of the decrease in potential energy is equal to the gain in total kinetic energy, or

$$mgh = \frac{1}{2} mv^2 + \frac{1}{2} I\omega^2 \quad (11.3)$$

where  $v$  and  $\omega$  are the linear and angular speeds of the disk when it reaches the bottom of the plane and  $I$  is the moment of inertia of the disk about its center of mass. Since the center of mass is moving steadily in a straight line, a point on the rim must be in rotation about it at the same angular velocity. Thus, the angular velocity and the linear speed are related through  $v = r\omega$ .

### 3. EXPERIMENTAL PROCEDURE

1. Set up the apparatus as shown in Fig.11.2. Connect the Smart Pulley photogate to your computer, and start up the computer.

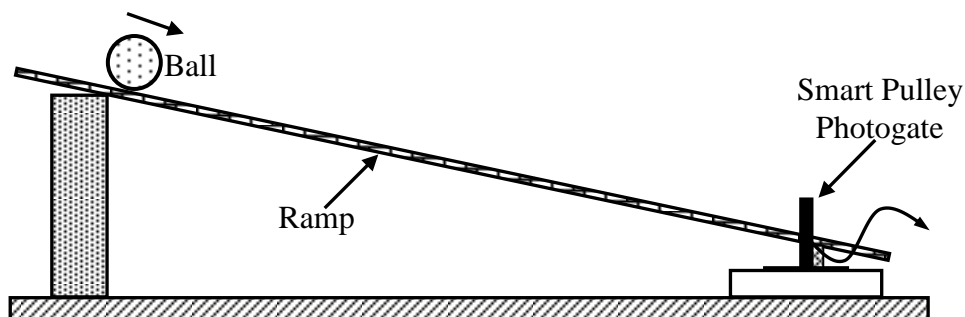


Figure 11.2: Equipment Setup

2. Move the ball slowly through the photogate, using the meter stick as shown in Fig. 11.3. Determine the point at which the ball first triggers the photogate timer-this is the first

point at which the LED turns ON and mark it with a pencil on the side of the channel. Then determine the point at which the ball last triggers the timer (the LED turns OFF), and mark this point. Measure the distance between these marks and record this distance as  $\Delta d$ . Determine the midpoint of this interval, and mark it in pencil on the channel.

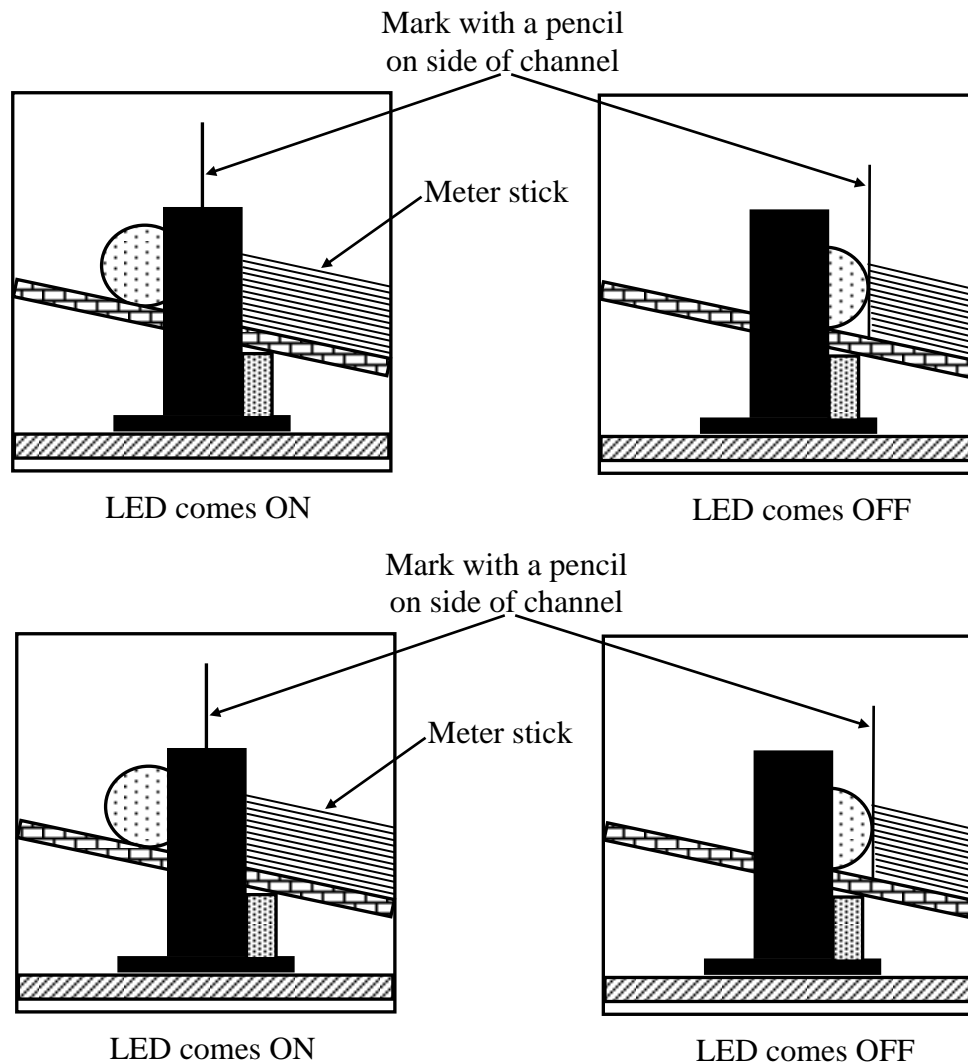


Figure 11.3: Measuring  $\Delta d$ .

3. Mark a starting point for the ball 30 cm up the ramp from your mid-point. Measure  $h_1$ , the vertical distance from the surface of the lab table to this point. Also measure  $h_2$ , the distance from the lab table to your mid-point (see Fig.11.4). Record these values in Table 11.1. The difference between these two heights determines the gravitational potential energy gained by the ball as it rolls from the starting point to the photogate. Record the difference in heights as  $\Delta h$ . Also record the distance along the ramp (30 cm) as  $d$ .
4. Mark a starting point for the ball 30 cm up the ramp from your mid-point. Measure  $h_1$ , the vertical distance from the surface of the lab table to this point. Also measure  $h_2$ , the

distance from the lab table to your mid-point (see Fig.11.4). Record these values in Table 11.1. The difference between these two heights determines the gravitational potential energy gained by the ball as it rolls from the starting point to the photogate. Record the difference in heights as  $\Delta h$ . Also record the distance along the ramp (30 cm) as  $d$ .

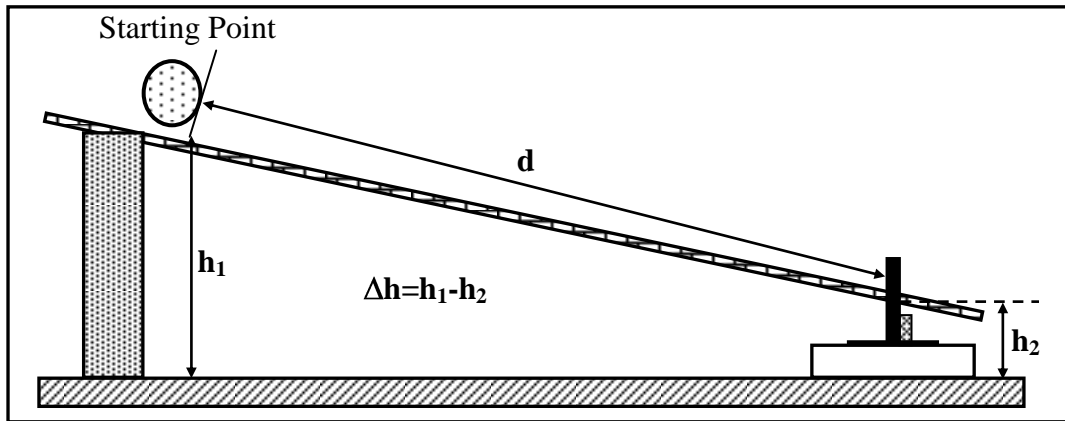


Figure 11.4: Measuring  $d$  and  $\Delta h$ .

5. Select option <G>, the gate function, from the Main Menu on the computer. Set the ball at starting point. Hold it at this position using a ruler or block of wood. Make sure the computer is not actively timing and is ready to take a new time. Release the ball so that it moves along the ramp and through the photogate. Record the time as Time 1 in Table 11.2.
6. Repeat your time measurement carefully 5 times, recording the time obtained in each trial.
7. Move the ramp to a different angle, and repeat steps 3-5. Do this for at least 3 angles.
8. Finally, measure the mass of your ball,  $m$ , the diameter of the ball,  $D$ , and the inside width of the ramp channel,  $W$ . Record these values on your data sheet, along with  $R$ , the radius of the ball ( $D/2$ ).

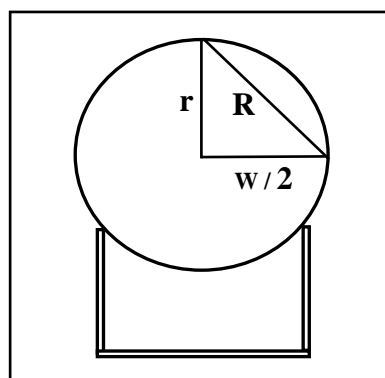


Figure 11.5: Determining  $r$

#### 4. DISCUSSIONS AND CONCLUSIONS

1. Calculate the average time obtained for each trial. Use your average time to determine the velocity of the ball as it passed through the photogate (Final Velocity= $\Delta d/t$ ).
2. For each trial, calculate the gravitational potential energy (GPE= $mg\Delta h$ ) that the ball had at the beginning. Also calculate the final kinetic energy, KE. Compare these two values.
3. You should have found a discrepancy between initial and final energies. For a rolling ball, the rotational kinetic energy, RKE= $\frac{1}{2}I\omega^2$ , where I is the moment of inertia of the ball and  $\omega$  is its rotational velocity. For the sphere,  $I=\frac{2}{5}mR^2$ . To solve for the RKE one must convert the translational velocity, v, into rotational velocity,  $\omega$ , using the relationship  $v=R\omega$ . Calculate the RKE and add it to the KE to verify conservation of energy.
4. If your figures are still not quite in agreement, a final tune-up is in order. The ball doesn't actually rotate on its full circumference. In figure 11.5, notice that the effective radius, r, is related to the overall radius, R, and the width of the channel, W, by the relationship:  $r^2=R^2-4(W/2)^2$ .
5. Recalculate the rotational energy, given that relationship between the linear velocity and the angular velocity is actually  $v=r\omega$ . At this point you have considered all of the mechanical energy forms possible, with the exception of the very small amount of energy that might have gone into heat due to friction.

#### 5. QUESTIONS

1. Why do car owners go to the trouble to balance automobile tires? What happens when car wheels are unbalanced.
2. Can a diver pull into a tuck and rotate while diving if he leaves the diving board with no angular velocity. Why?
3. What would happen to the planets if the gravitational force had a tangential component as well as radial component
4. Explain how ice skaters can quickly go from a slow to a fast spin and vice versa. What happens to their angular velocity and their moment of inertia Is an external torque required.
5. A ball rolls across the floor. Is it possible for its translational and rotational kinetic energies to be the same?
6. Two spheres of equal mass are released from rest at the top of an inclined plane. One sphere is solid and uniform density. The other sphere is a shell of uniform density. (a)

Which sphere reaches the bottom of the plane first? (b) Which sphere will have the greatest translational kinetic energy at the bottom?

7. About what axis would a uniform cube have its minimum rotational inertia?
8. A solid wooden sphere rolls two different inclined planes of the same height but with different angles of inclination. Will it reach the bottom with the same speed in each case? Will it take longer to roll down one incline than the other? If your answer is yes to either question, explain why.

Data from accelerating ball: $\Delta d =$ _____  $m =$ _____  $D =$ _____  $W =$ _____	<b>Table 11.1: Measuring <math>\Delta h</math></b>			
	Trial	$h_1$	$h_2$	$\Delta h$
	1			
	2			
	3			
	4			
	5			
	6			

<b>Table 11. 2: Measuring of trials</b>					
Quantity	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
d					
Time 1					
Time 2					
Time 3					
Time 4					
Time 5					
Average					
Time					
Final					
Velocity					
GPE					
KE					



