NAME ______________________ LAB PARTNERS ______________________

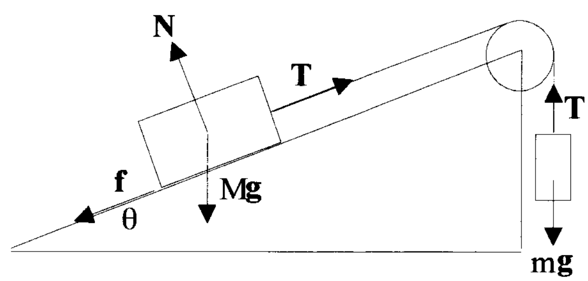
Station Number ______________________ ______________________

Newton's Second Law of Motion *Experiment 10*

INTRODUCTION

A net force $\mathbf{F}_{net}$ acting on an object produces an acceleration **a** in the direction of the force directly proportional to the force and inversely proportional to the mass *m* of the object. In equation form this statement becomes, $\mathbf{F}_{net} = \Sigma\mathbf{F} = m\mathbf{a}$. Notice that both **F** and **a** are vectors, but *m* is a scalar (number). The objects of this experiment are to learn to apply Newton's second law of motion and to use to find useful information about the forces acting. You will measure both the coefficients of rolling friction and sliding friction.

THEORY



The system to be studied is shown in the figure. A mass M rests on an inclined track and is attached to a second mass m by a string that passes over a pulley. The pulley and the string are so light that their mass or rotational inertia may be neglected. The forces that act on each mass are shown and identified as follows: **T** is the tension in the string, *m***g** is the weight of mass *m*, **N** is the normal force of contact between the track and *M*, *M***g** is the weight of mass *M*, and **f** is the force due to friction (rolling or sliding). The equation of motion parallel to the track for mass *M*, a dynamics cart (or wooden block) in this experiment, is given by

$$T - Mg \sin \theta - f = Ma. \tag{1}$$

The equation of motion for the hanging mass is given by

$$mg - T = ma, \tag{2}$$

where we have assumed quantities positive up along the track and down from the pulley. The equation of motion for the mass *M* perpendicular to the track is given by

$$N - Mg \cos \theta = 0. \tag{3}$$

For both rolling friction and sliding friction, it is possible to relate the magnitude of the friction force f to the normal force of contact between the surfaces so that $f = \mu_r N$ for rolling friction and

$f = \mu_k N$ for sliding (kinetic) friction. By measuring a, M, m, and θ, one can calculate f, T, N and finally μ_r and μ_k.

The forces that act in this experiment may be considered constant so that one can use the equations for constant velocity and constant acceleration. The acceleration will be calculated from the position versus time curve for the motion of the masses m and M.

EXPERIMENT NO. 10

1. Level the track by adjusting the screws on the feet of the track.

2. Remove the feet on the initial side of the track. The track will remain inclined during the experiment; we will record data as the cart and wooden block move up the inclined track.

3. Carefully measure the angle of inclination of the track.

   Angle = _______

4. In the first part of the experiment, we will obtain data to calculate the coefficient of rolling friction for the dynamics cart. Use the balance to find the mass of the cart and the weight hanger. Add about 15 grams to the weight hanger. This should be enough to cause the cart to accelerate up the track. The mass of the weight hanger plus the added 15-gram mass corresponds to the mass m in the drawing. Record these values below

   Weight hanger mass _________ + Added mass _________ = total mass (m) __________

   mass of the cart (M) = ______________

5. Log into the Student account and open the **exp9** file from the Start Menu.

6. Before each time data are acquired, place the cart at the starting position, release it and click **Start** to record data. Click again to stop recording data before the cart reaches the end of the track. Collect your first data set.

7. Your data set contains the position as a function time of the cart as it moved up the track. To view a graph of your data, drag the data set **Run #1** onto the **Graph** header in the **Display** window below.
   You should now see a graph of position vs. time. Since these data represent motion with constant acceleration the graph will not be a straight line. If your data look fine close the graph.

8. We now want to look at the graph of velocity as a function of time. Remember that velocity is defined as **v = dx/dt**. Before we create the graph of v vs. t

   Click on the **Calculate** button at the top of the screen and select **New**. Under **Definition** type "dx = x-last(1,x)", as shown in the figure below, and click **Accept**. This definition uses the special function "last" to calculate the difference between two adjacent values of the variable x, ($x_2 - x_1$). If you are asked to define the variable x, simply drag **x (m)** to where it says "Please import the variable x" under **Variables**

9. Now set the variable name and the units of dx, click **Properties** in the **Calculator** window then type "m" under **Units**. Under **Variable Name** type "dx". Click **OK**.

10. Similarly, we are going to create the variable dt. Click on **New** in the **Calculator** window. Type "dt = t-last(1,t)" under definition and click **Accept**. If asked to define the t, click on "t = timeof(x)" in the **Data** window and drag it to define the variable.

11. Click **Properties** in the **Calculator** window and type "s" under **Units**. Click on the drop down button besides **Variable Name** and select Y, erase it and type "dt". Click **OK**.

12. Create the variable v by clicking **New** in the **Calculate** window and typing "v =dx/dt" under **Definition**. To set the units of v click **Properties** in the **Calculator** window and type "m/s" under **Units**. Click the button besides **Variable Name** and select Y, erase it and type "v".

    Then click the button again, this time select X, erase it type "time". Then type "s" under **Units**. Click **OK**.

13. To plot the graph of v vs. t drag "v = dx/dt" on the **Data** window and drop it on **Graph** in the **Display** window. The graph should be a straight line since it is described by the equation $v = v_0 + at$.

    Eliminate the line connecting the data points, click **Display** on the menu at the top of your screen and select **Settings**. Uncheck the box that says "Connect Data Points" and click **OK.**

14. Print the graph, draw the best fit line through it and calculate the slope. Record both the slope and the v-intercept. Show all your calculations on the graph print out.

Slope = ____________ v-intercept = ____________

15. We are now going to use the computer to fit the data. DataStudio will fit the data to the "best" straight line, thereby minimizing the error you might make in eyeballing the best straight line. Such a process is called the least squares fit to a straight line. Click **Fit** on the graph window and select **Linear Fit**, a small window will appear with information the values of the fitting parameters. Write down the value of the slope and intercept, the results should be very close to the ones obtained in the previous step. If you only want to fit part of the data highlight the interval that you want to consider and then use **Linear Fit.**

Slope = ____________ v-intercept = ____________

16. Print your graph again, now showing the least squares fit obtained. The equation $\upsilon = \upsilon_0 + \alpha t$ describes velocity as a function of time for an object moving with constant acceleration.

What do the slope and v-intercept represent?

Calculate the percent of difference between the values for acceleration and initial velocity found by constructing the best fit by hand and the values generated by **DataStudio.**
Show your work.

% diff in a = ____________ *% diff* in v_0 = ____________

17. Use Equations (1) and (2) to eliminate T and show that the expression for f is given by

$$f = g\,(m - M \sin \theta) - (m + M)\,a \qquad (4)$$

18. Use all the data you have acquired, set $g = 9.8\ m/s^2$, and find the rolling friction force f. Use Equation (3) to find the normal force and calculate the coefficient of rolling friction μ_r. Fill in the spaces below and show all work in the space below.

$f =$ ______________ $N =$ ______________ $\mu_r =$ ______________

19. Now we will carry out the same procedure to calculate the coefficient of sliding friction for the wooden block (felt side down). Determine the mass (M) of the wooden block and record it. Then replace the cart with the wooden block.

Mass of wooden block______________

20. Add about 40 grams to the weight hanger and record the total hanging mass m.

Hanging mass (m) = ___________

21. Record a data run now using the wooden block. The graph of velocity vs. time will be created automatically.

    Use this graph to obtain the acceleration of the block as it moves up the track using the **Linear Fit** function only. Find the friction force, normal force, and coefficient of sliding friction μ_k. Record these values below and show all work in the space below.

f = ______________ N = ______________ μ_k = ______________

Logout of the computer.

QUESTIONS

1. Calculate the tensions in the string for both the cart and the wooden block.

2. Use the value obtained for the cart's coefficient of rolling friction and determine how far it will travel if given an initial speed of 20 cm/s across a flat, level surface.