Kinetic Friction

Objective: The purpose of this experiment is to study the force of kinetic friction. Kinetic friction is one of many non-conservative (i.e., retarding) forces present in most real systems. Kinetic friction results whenever two *moving* surfaces are in contact with each other. Other examples of frictional forces are static friction and air drag. In this experiment you will determine how kinetic friction is related to velocity, acceleration, surface area and mass.

Physics Theory: Consider the system shown in Figure 1. A block of mass M is placed on a level table and connected to a mass m by a light string running through a pulley. If mass m is released, it will start to fall and the wooden block will be pulled across the table. A free body diagram of this system is shown in Figure 2.

We begin our analysis of this system by writing equations to resolve forces in the x and y directions. Notice that the pulley in Figure 1 has the effect of redirecting the force labelled as T on M from the horizontal direction (along the $+x$ axis) to the vertical direction (positive y axis) on m.

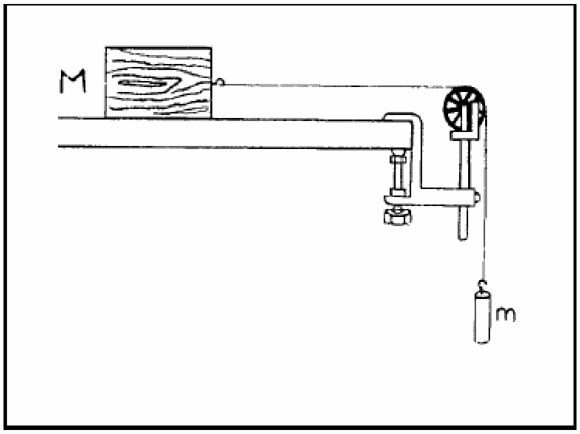

Figure 1

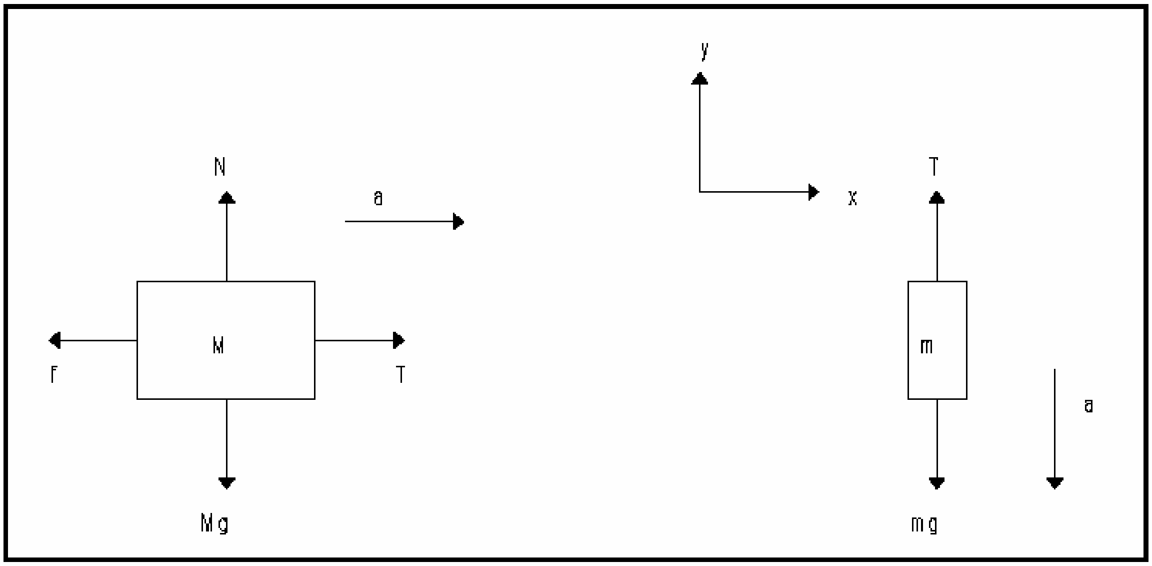

Figure 2. Free-body diagram for frictional force experiment.

If T is the tension in the cord, f the retarding force due to friction between the block and the table, then for mass M:

$$\Sigma F_x = T - f = Ma \qquad (1)$$
$$\Sigma F_y = N - Mg = 0 \qquad (2)$$

and for mass m:

$$\Sigma F_x = 0 \qquad (3)$$
$$\Sigma F_y = T - mg = -ma \qquad (4)$$

Because T is the same in both sets of equations we can combine (1) and (4):

$$\Sigma F = Ma + f = mg - ma \qquad (5)$$

and since a is also the same everywhere in this system:

$$\Sigma F = (M + m)a = mg - f \qquad (6)$$

The frictional force f has a magnitude given by:

$$f = \mu_k N = mg - (M + m)a \qquad (7)$$

where by (3) $N = Mg$. Solving for the coefficient of kinetic friction (μ_k):

$$\mu_k = \frac{f}{N}$$

$$\mu_k = \frac{mg - (M + m)a}{Mg} \qquad (8)$$

In general, the coefficient of kinetic friction μ_k depends only upon the nature of the surfaces that are in contact with each other. From (8) we can see that μ_k for various materials may be measured by setting up a system such as that in Figure 1, measuring M and m, and measuring a after the system is released from rest.

Experimental: In this experiment, you will use the PASCO 500 Interface, the Precision Timer program, and a Smart Pulley. The Smart Pulley uses a photogate to convert analog data (the speed and number of rotations of the pulley) to a digital form that may be processed by a computer. Your lab instructor will help you set up the equipment you need for this experiment.

- Turn on the interface, Turn on the computer, and enter the WINDOWS environment.

- Open the 113/213 folder, double click on the Atwood's Machine or Friction, depending on your lab.

- Wait until the interface is found and states that it is okay to start the experiment.

- Click the “start” button to start taking data and click the “stop” button to stop taking data

- Observe that all the graphs appear on the screen at the same time

- When finished, close program and “do not” save any changes.

The graph will be displayed. If you were not quick enough to stop timing before the hanger hit the floor you may end up with extraneous data points. These may be eliminated with the Delete Data option.

Recall that acceleration may be written $\Delta v/\Delta t$. The slope of the line on a velocity vs. time graph is:

$$slope = \frac{v_f - v_i}{t_f - t_i} = \frac{\Delta v}{\Delta t} = a$$

i.e., the slope of this graph represents the acceleration of the system. Because acceleration is constant in this system (as well as most others) your data points should lie in a fairly straight line. Because of *random error* present in the experiment you will probably not get data points that lie exactly along a straight line. The computer will fit the best straight line that it can through your data points. A correlation coefficient R will be listed with the statistics for your graph. The closer this value is to 1.00, the better your data fits to a straight line. Any data set with R values below 0.997 should probably be rejected.

Recall that any straight line may be plotted with a general equation of the form $y = mx + b$, where m represents the slope of the line and b the y axis intercept. The computer will give values for m and b along with R for each graph. The value the computer gives for m is the acceleration of the system.

Set up a table with columns for m, a, μ_k, and R. Measure mass M and record it at the top of the table. Repeat this procedure at least 10 times using different values for m (Note: try increasing m in 5 gram increments). Compute the mean and standard deviation of μ_k.

- Repeat this procedure but turn block M on its side to decrease the surface area in contact with the table. Use the same values for m that you used before. What effect should this have on μ_k (look at eq. 8)? What do your measurements tell you? Does your prediction match your data?

By now you should realize that μ_k depends only upon the physical properties of the surfaces in contact with each other and the contact force holding them together. Rough or sticky surfaces will not usually glide smoothly past one another. And any pair of surfaces, given a great enough contact force, will similarly resist gliding smoothly. Since you were measuring μ_k for wood on wood with the same contact force (mass *M* remained constant) you should have recorded fairly consistent values for μ_k. If the numbers you recorded for your two measurements of μ_k are not the same, how do you decide if the difference is significant?

This is a situation where experimental statistics provide the remedy. The mean values for each of the two sets of measurements you made above are probably not exactly the same. So are they consistent? The answer lies in the standard deviation if each mean value. If the standard deviations overlap, the measurements are, for all intents and purposes, the same. Make a one dimensional plot of your mean values in your lab notebook similar to Figure 3.. Above each mean value draw error bars for the standard deviation. If the error bars overlap then your

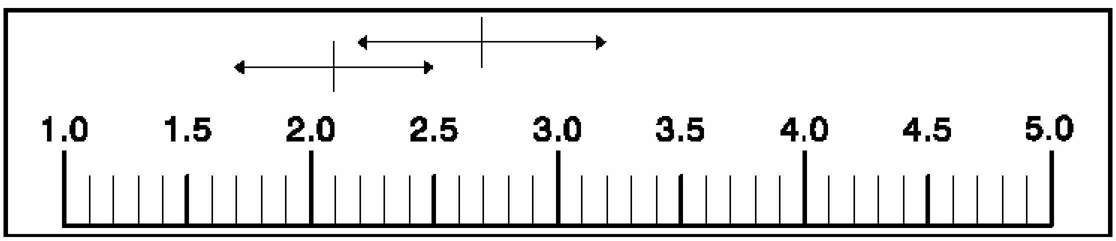

Figure 3. Overlapping values of σ. The two measurements are 2.1 ± 0.4 and 2.7 ± 0.5. The mean values are statistically the same.

measurements are within a standard deviation of each other and are statistically the same. Are your measurements for μ_k consistent?

- Return mass *M* to its original orientation but double its mass by placing another block of equal mass on top of *M*. Double the values you previously used for *m* and repeat the experiment.

How does this affect μ_k?

- Figure 4 shows another experimental setup one could use to measure the value of μ_k. It is not necessary for you to actually set up this experiment. What you are to do in the time that remains is to draw a free body diagram of this system and derive an equation for μ_k as was done for you at the beginning of this procedure. Would you expect to obtain values for μ_k consistent with those you obtained in the procedure you just carried out? Why or why not?

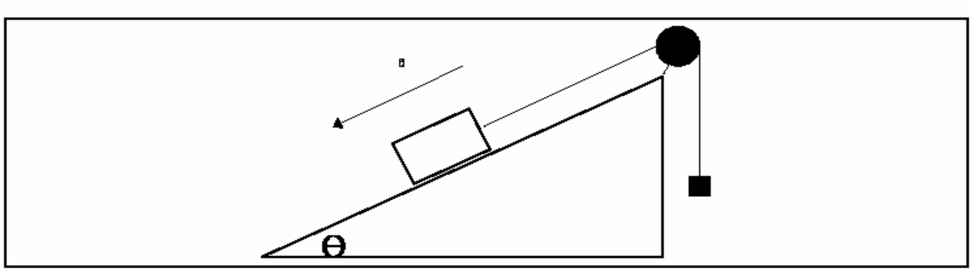

Figure 4