Experiment # 10

Kinetic Friction
The Coefficient

Principle

Definition and Elementary Properties

Friction is a force. The sole purpose of this force is to impede motion. As such, it is always directed opposite the velocity vector. Force of friction is created when surfaces of two solids come in contact with one another. Thus the resistance offered to a solid object moving through air or water, is not friction. In Fig (1), the directions of the force of friction F_{fr} , are shown for a number of different situations. Please note, very carefully, that the direction of F_{fr} is completely unrelated to the directions of other forces. To determine the direction of F_{fr} , therefore, we need identify the direction of motion of the object (actual or anticipated) and draw an arrow for the velocity vector. The arrow for F_{fr} is then drawn in the opposite direction.

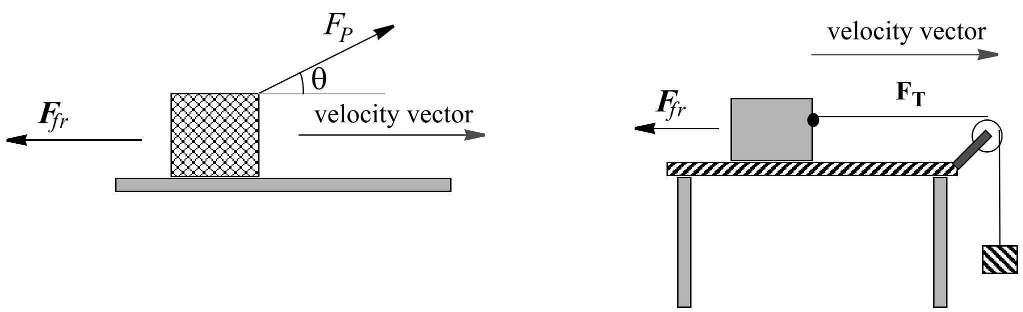


Fig (1) Direction of Force of Friction on Flat Surfaces

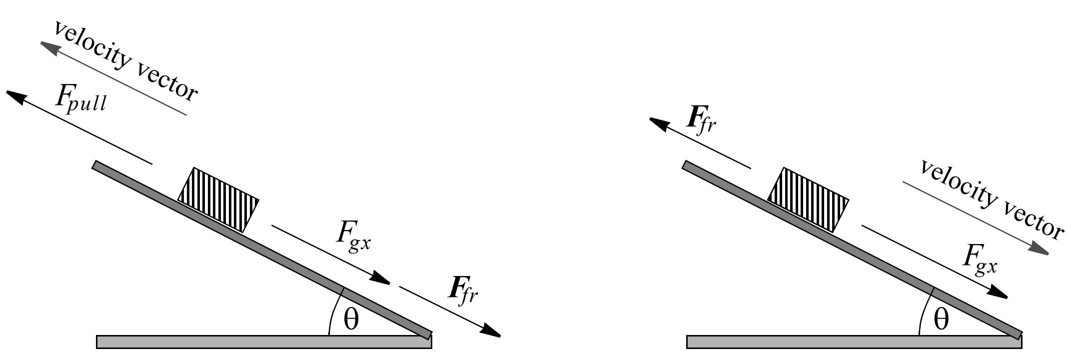


Fig (2) Direction of Force of Friction on Inclined Planes

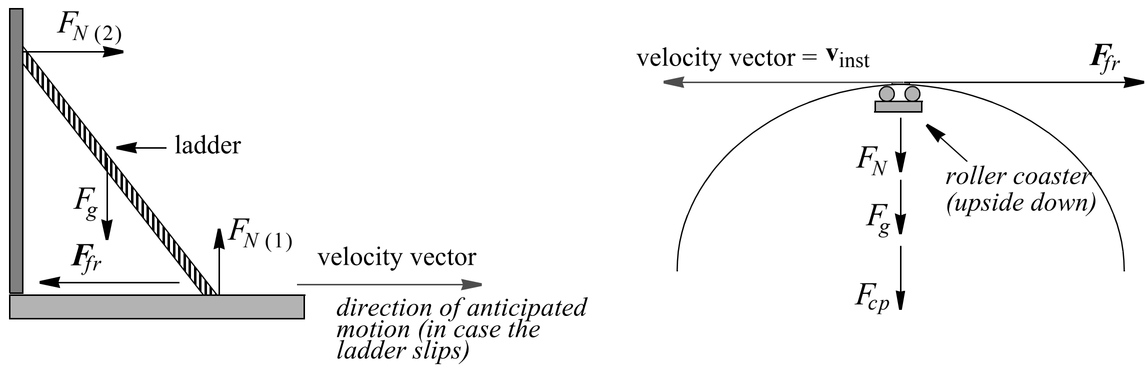


Fig (3) Direction of Force of Friction Elsewhere

Nature of the Force of Friction

Surfaces of objects are never absolutely smooth. If viewed under a suitable microscope each surface, no matter how smooth, will be found to have ridges and trenches. When two such surfaces come in contact with one another, the ridges of one get hooked up (or bonded) to the trenches of the other surface and vice versa. Force is required to break these bonds and hook-ups. This force is the force of friction. Friction causes mechanical energy to be converted to thermal energy irreversibly.

Forces of friction are of two types.

(1) Kinetic Friction, $\boldsymbol{F}_k$. It is also known as sliding (or skidding) friction. In this case, the two surfaces slide against each other, giving rise to rubbing. As rubbing proceeds, a point on one surface remains in contact with *several* points of the other surface. For one pair of surfaces $\boldsymbol{F}_k$ will have only one value.

(2) Static friction, $\boldsymbol{F}_s$. In this case, the parts of the two solid objects that are in contact with one another, remain at rest and, as such, have no motion relative to each other. The two objects may either be completely at rest (such as a book resting on a table) or may be rolling without slipping. When rolling, a point on the surface of the rolling object makes a momentary contact with *one* point of the surface upon which it rolls. The two points stay at rest with respect to one another, momentarily; and then they part. As rolling continues, two other (different) points, one from each surface, make similar momentary contact with one another. This process continues. As each pair of points (one from each surface) *stays at rest* with respect to one another, the friction is of the static type and not of the kinetic type, as one would expect. Unlike kinetic friction, static friction does not have a fixed value for a given pair of surfaces. But it does have a maximum value. This shows up when we try to set a stationary object in motion.

Magnitude of Force of Friction

Force of friction is found to depend on the normal force $\boldsymbol{F}_N$: We write:

$$F_{fr} \propto \boldsymbol{F}_N \qquad \text{..........(1)}$$

$$F_{fr} = \mu \boldsymbol{F}_N \qquad \text{..........(2)}$$

μ is known as the *coefficient of friction.* It is a direct measure of the relative smoothness of the concerned surfaces. For all every-day surfaces, μ is less than one. In case a motion takes place on things like gravel, μ can exceed unity. For the two types of friction, we write:

$$F_k = \mu_k F_N \qquad F_s \leq \mu_s F_N$$

Additionally, force of friction is found to be independent of the area of surface of contact between the two objects.

Objectives of the Experiment

To determine the value of the coefficient of kinetic friction μ*, between the surface of the given block and the surface of the inclined plane.*

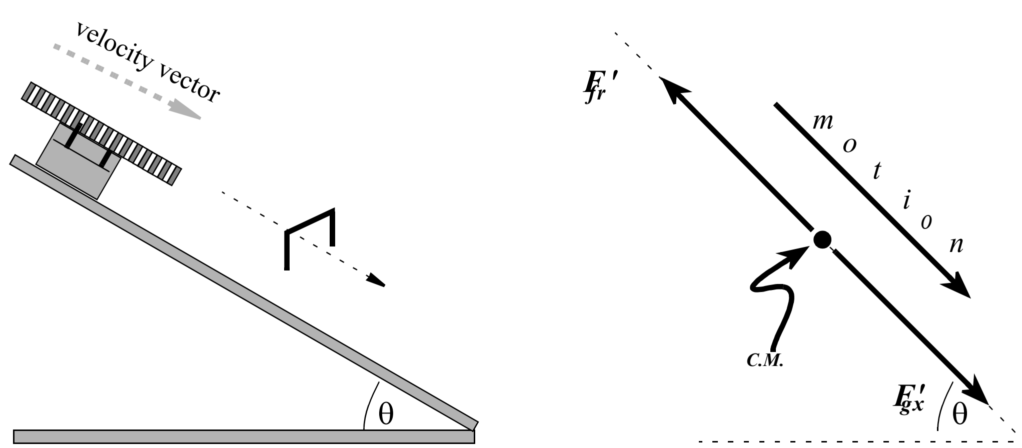
(The objective may be modified by the instructor.)

Setting up

Direct determination of $\boldsymbol{F_{fr}}$ (and hence of μ) will require an accelerated motion of the given block and one will have to determine the extent by which this motion is impeded by friction.

One way of doing this will be to pull the block manually by applying a mathematically uniform force of pull $\boldsymbol{F_{pull}}$, for a finite length of time. Knowing $\boldsymbol{F_{pull}}$ and measuring the net force on the block, $\boldsymbol{F_{net}}$, one can find $\boldsymbol{F_{fr}}$. Now, we know that it is impossible to apply a mathematically uniform $\boldsymbol{F_{pull}}$, manually, for a finite length of time, so we shall have to let the earth do the pulling for us. Need we remind you that earth's force of pull $\boldsymbol{F_g}$, is infinitely uniform. This can be done in two ways: (i) using the arrangement with suspended mass, cord and pulley. (ii) using an inclined plane.

The use of inclined plane is preferable because it does not need suspended mass and the related paraphernalia. We may just let the block slide down the inclined plane and measure the acceleration directly using the smart timer. The suggested arrangement is shown in Figs (4).



Gig (4) Block Sliding Down

Measuring Accelerations

The *acceleration plate* (called *picket fence*) has15 windows with 16 non windows. Each of these are precisely 0.500 cm wide. The d values, therefore, are 1.00 cm, 2.00 cm, 3.00 cm........ 16.00 cm. One need not measure these distances because the plate has been precisely cut using a laser guided cutting tool. The timer has been programmed to record Δt values for these 15 d values. Thus Δt_1 is for 1.00 cm, Δt_2 is for 2.00 cm,..... and Δt_{16} is for 16.00 cm. After the windows plate has cleared the photogate, we may use the *calc* key to read the half-acceleration of the block.

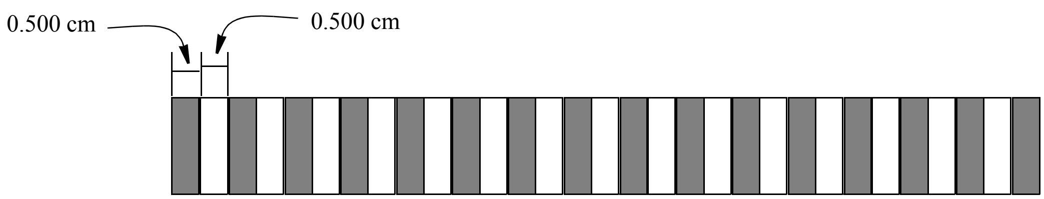


Fig (5) The Acceleration Plate or the Picket Fence

Mathematical Analysis

For the downward journey, as shown in Fig (4), the net force is:

$$\boldsymbol{F_{net}} = \boldsymbol{F_{gx}'} - \boldsymbol{F_{fr}'} \qquad \text{..........(3)}$$

$$F_{net} = m\boldsymbol{g}\sin\theta - \mu m\boldsymbol{g}\cos\theta$$

Applying Newton's second law:

$$mg\sin\theta - \mu mg\cos\theta = ma_{down}$$

$$a_{down} = g\,\sin\theta - \mu g\,\cos\theta \qquad \text{..........(4)}$$

Dividing both sides by $g\sin\theta$, we get:

$$\frac{a_{down}}{g\sin\theta} = 1 - \mu\,\cot\theta \qquad \text{..........(5)}$$

This equation is comparable to the equation of a straight line, we find that $\angle\theta$ is the independent variable. while a_{down} is our dependent variable. Accordingly, we shall select 15 different values of $\angle\theta$ and for each determine values of a_{down} directly from timer 2000. A graph of

$$\frac{a_{down}}{g\sin\theta} \text{ vs. } \cot\theta$$

will yield a straight line of (negative) slope μ and a y-axis intercept of unity. Unity here really stands for the value of *acceleration due to gravity* $\boldsymbol{g}$. It is very important that our experiment yield a y-axis intercept of unity.

Apparatus Required

(1) Inclined plane (about 80 cm long) with a *guide* to allow the block to slide down in a straight line. It should be mounted on a *jack* for controlling angles of inclination.

(2) Block of wood to which the *picket fence* is attached

(3) Picket Fence.

(4) Photogate with 1.00 mm beam and capability of setting desired gap lengths.

(5) Smart Timer

(6) An arrangement with two meter sticks to measure the angle of inclination using $\tan\theta$.

A Suggested Experimental Arrangement

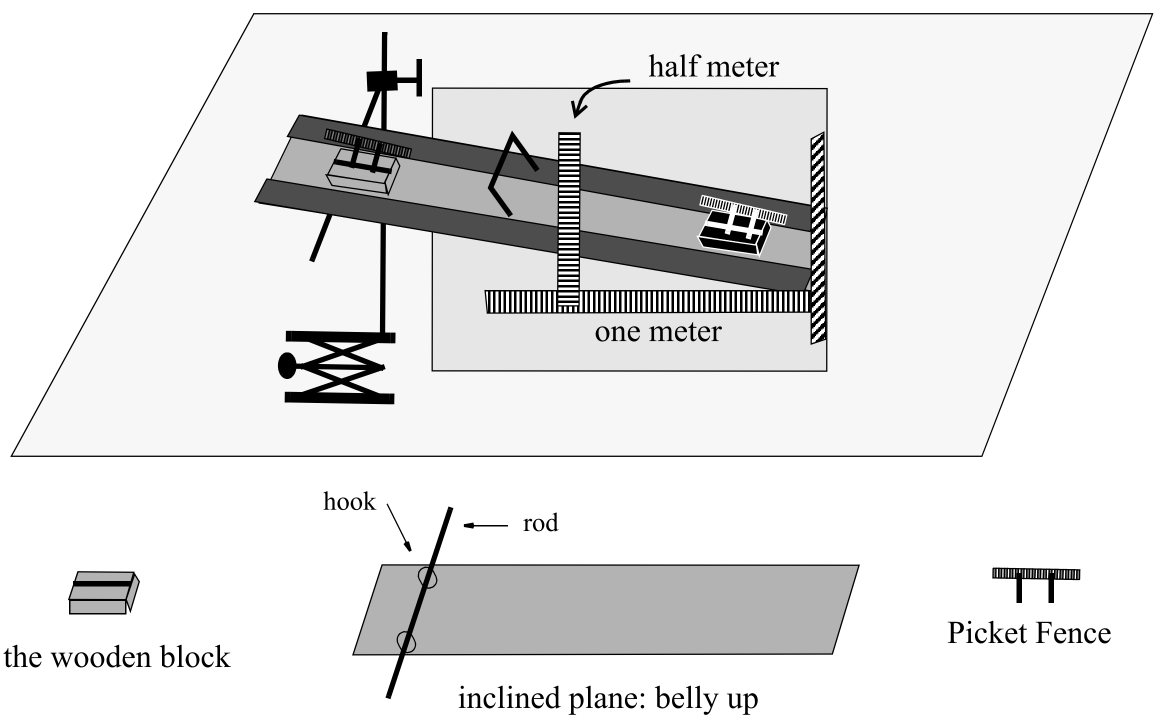


Fig (6) A suggested inclined Plane

Procedure

1) Set the inclined plane at the angle suggested in the data sheet for trial #1.
2) Set up the photogate at about 30 cm away from the starting position of the block. Make sure that the windows plate passes through the photogate comfortably. The gap of the photogate should be about one centimeter.
3) Select *acceleration mode* from the timer's menu. Select 4 decimal places for the display.
4) For each angle of inclination, let the block slide down from the top of the inclined plane.

Make sure you let the block slide down from the same position in all trials. After the plate has cleared the photogate, stop the block manually, gently.

5) Press the *calc* key and check for coefficient a_o to be zero and r^2 to be 1.0000. If the two values are respectively *zero* and *one*, record the values of half-acceleration and the initial velocity (for the instant the infra-red beam is interrupted).

Some latitude in the values of a_o and r^2 may be permitted. Ask the instructor about it.

6) Repeat the trial three more times for a total of four *slidings* for this angle.

7) Set the inclined plane for the next angle by raising the jack by 1.00 cm on the vertical half-meter stick. Repeat steps (4), (5) and (6).

8) Repeat step (7) for the remaining angles. Sixteen angles, altogether.

(9) The experiment ends. Set the inclined plane at some small angle so that it does not trip. Switch off the timer. Arrange everything neatly on the table.

Calculations and Graphs

Pre graph Calculations (Should be carried out on the computer itself)

(i) From each set of 4 trials for each angle, choose the smallest value of half-acceleration. The idea is to look for the maximum effect of friction. When the effect of friction is maximum, the acceleration will be minimum.

(ii) Multiply each half-acceleration value (one for each of the sixteen angles) by 2 to get full acceleration values. These are a_{down} values.

(ii) Calculate each angle using

$$\theta = \tan^{-1}\left(\frac{opp}{Adj}\right)$$

where *adjacent* side is always 30 cm,

(iv) Calculate $\sin\theta$ for each of the 16 angles.

(v) Calculate $\cot\theta$ for each of the 16 angles

(vi) Calculate

$$a_{down}/(g\sin\theta)$$

for all 16 trials

Graph

Plot a graph of $a_{down}/(g\sin\theta)$, (on y-axis), against $\cot\theta$, on a computer using the *crick-etgraph* program. Instruct the computer to fit a straight line and then to print the equation of the straight line together with the value of r^2, the coefficient of determination. You should have five significant decimal digits in the computer print out. Record the value of slope from the computer print out, into your lab sheet.

Post graph Calculations.

(i) The slope of the straight line is in fact the required coefficient of friction μ. The slope is expected to be negative but we shall ignore the negative sign. The value of μ is a positive quantity.

(ii) The y-axis intercept of the graph should be unity. This is very important. A large deviation from unity, will invalidate all results

Results

(i) We explain the *unity* as the expected value of g in units of g. This why it has the value *one* (unity) and has no units. Make a table to compare the *expected value of g in units of g* with the one obtained from the y-intercept of the straight-line equation, printed out by the computer, As stated above, this expected value is *one*.

(ii) Enter the value of μ, (found from the slope), as the *coefficient of friction*. There is no *expected* value. We cannot, therefore, make a table of comparison and cannot find percent difference (or error).

Conclusions and Discussions

One of the points you need to discuss here is that how reliable your result is. How confident you are that the value of μ that you found is really acceptable. The test of authenticity is how close your *expected value of g in units of g* is to unity. If it is better than 99%, you should be quite confident.

What Did You Learn in this Experiment?.

A hearty and thoughtful account of what you learned in this experiment by way of the principle and the techniques of experimentation, should be given

Data & Data Tables

Name.................................... **Date**..............................

Instructor.............................. **Lab Section**...................

Partner.......................... **Table #**..........................

Position of the-half meter stick on the one-meter stick: 30 cm
(this is the adjacent side for the calculation of angle θ)

#	the *opposite* side (cm).	half-acceleration (m/s^2)	Initial Velocity v_o (m/s)	Coefficient x_o (m)	Coefficient of Determination r^2
1	30.50				
2	29.50				
3	28.50				
4	27.50				
5	2650				

#	the *opposite* side (cm).	half-acceleration (m/s^2)	Initial Velocity v_o (m/s)	Coefficient x_o (m)	Coefficient of Determination r^2
6	25.50				
7	24.50				
8	2 350				
9	2 2.50				
10	21.50				
11	20.50				
12	19.50				

#	the *opposite* side (cm).	half-acceleration (m/s^2)	Initial Velocity v_o (m/s)	Coefficient x_o (m)	Coefficient of Determination r^2
13	18.50				
14	17.50				
15	16.50				
16	15.50				

Space for additional data (if needed)