

Lab Manual
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INTRODUCTION

When a body slides over a rough surface a frictional force generally develops which acts to impede the motion. Friction, when viewed at the microscopic level, is actually a very complicated phenomenon. Nevertheless, physicists and engineers have managed to develop a relatively simple empirical law of force which allows the effects of friction to be incorporated into their calculations. This law of force was first proposed by Leonardo da Vinci (1452-1519), and later extended by Charles Augustin de Coulomb (1736-1806) (who is more famous for the discovering the law of electrostatic attraction). The frictional force exerted on a body sliding over a rough surface is proportional to the normal reaction R_N at that sur-face, the constant of proportionality depending on the nature of the surface. In other words,

$$f = \mu R_N \quad (1.)$$

where μ is termed the coefficient of (dynamical) friction. For ordinary surfaces, μ is generally of order unity.

Consider a block of mass m being dragged over a horizontal surface, whose coefficient of friction is μ , by a horizontal force F . See Fig. 1. The weight $W = m g$ of the block acts vertically downwards, giving rise to a reaction $R = m g$ acting vertically upwards. The magnitude of the frictional force f , which impedes the motion of the block, is simply μ times the normal reaction $R = m g$. Hence, $f = \mu m g$. The acceleration of the block is, therefore,

$$a = \frac{F - f}{m} = \frac{F}{m} - \mu g$$

assuming that $F > f$. What happens if $F < f$: i.e., if the applied force F is less than the frictional force f ? In this case, common sense suggests that the block simply remains at rest (it certainly does not accelerate backwards!). Hence, $f = \mu m g$ is actually the maximum force which friction can generate in order to impede the motion of the block. If the applied force F is less than this maximum value then the applied force is canceled out by an equal and opposite frictional force, and the block remains stationary. Only if the applied force exceeds the maximum frictional force does the block start to move.

Consider a block of mass m sliding down a rough incline (coefficient of friction μ) which subtends an angle Θ to the horizontal, as shown in Fig 1. The weight mg of the block can be resolved into components $mg \cos \Theta$, acting normal to the incline, and $mg \sin \Theta$, acting parallel to the incline. The reaction of the incline to the weight of the block acts normally outwards from the incline, and is of magnitude $mg \cos \Theta$. Parallel to the incline, the block is subject to the downward gravitational force $mg \sin \Theta$, and the upward frictional force f (which acts to prevent the block sliding down the incline). In order for the block to move, the magnitude of the former force must exceed the maximum value of the latter,

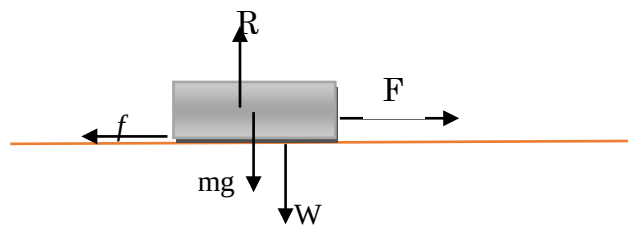


Figure 1: Friction

which is μ time the magnitude of the normal reaction, or $\mu mg \cos \Theta$. Hence, the condition for the weight of the block to overcome friction, and, thus, to cause the block to slide down the incline, is

$$mg \sin \Theta > \mu mg \cos \Theta \quad (3.)$$

or

$$\tan \theta > \mu. \quad (4.)$$

In other words, if the slope of the incline exceeds a certain critical value, which depends on μ , then the block will start to slide. Incidentally, the above formula suggests a fairly simple way of determining the coefficient of friction for a given object sliding over a particular surface. Simply tilt the surface gradually until the object just starts to move: the coefficient of friction is simply the tangent of the critical tilt angle (measured with respect to the horizontal).

As the angle of an inclined plane (i.e., ramp) is raised, at some critical angle called the angle of repose, an object placed on the inclined plane will just start to slide down the plane at a constant speed (i.e., zero acceleration). At the angle of repose, the coefficient of friction between the object and the plane equals the height of the ramp divided by the base of the ramp.

Up to now, we have implicitly suggested that the coefficient of friction between an object and a surface is the same whether the object remains stationary or slides over the surface. In fact, this is generally not the case. Usually, the coefficient of friction when the object is stationary is slightly larger than the coefficient when the object is sliding. We call the former coefficient the coefficient of static friction, μ_s , whereas the latter coefficient is usually termed the coefficient of kinetic (or dynamical) friction, μ_k . The fact that $\mu_s > \mu_k$ simply implies that objects have a tendency to "stick" to rough surfaces when placed upon them. The force required to unstick a given object, and, thereby, set it in motion, is μ_s times the normal

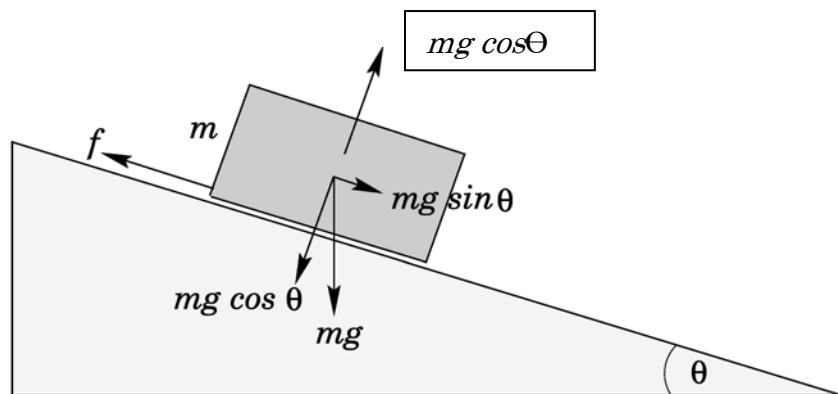


Figure 2: Block sliding down a rough slope

reaction at the surface. Once the object has been set in motion, the frictional force acting to impede this motion falls somewhat to μ_k times the normal reaction.

When $a = 0.0 \text{ m/s}^2$, the force probe measures the force necessary to counteract friction and thus is equal to F_f .

If the block is pulled at constant velocity, starting from rest, there is a "bump" at the beginning of the graph, and the remaining graph is, on average, horizontal. The bump at the beginning of the graph is a result of

overcoming the maximum static friction, f_{max} , which is usually greater than kinetic friction, f_k . The maximum value of this bump allows us to determine μ_s . The horizontal portion of the graph, f_{avg} , allows us to determine μ_k . A sketch of how your graph should look is shown in Fig. 3. Note that the force begins at zero newtons.

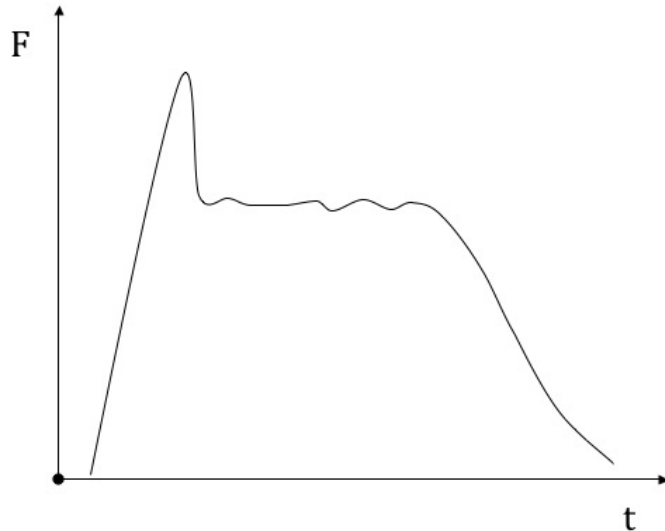


Figure 3: Sample Force vs. Time graph

Read University Physics Volume 1 Chapter #6: APPLICATIONS OF NEWTON'S LAWS

Angle of friction

PART ONE: Coefficient of Friction and Angle of Repose

MATERIALS

1. The meter stick (e.g., a yardstick with a metric scale on one side).
2. A clothes button.
3. A coin.
4. A wooden toothpick.

PROCEDURE

1. Place the meter stick on the floor or a table.
2. Place a coin on the meter stick and slowly tilt the meter stick, increasing the angle slowly. When the coin just starts to slide down the meter stick at a constant speed, measure how high the edge of the meter stick is above the ground or table.
3. Enter your data to the data table.⁴
4. Perform this experiment 5 times with each object.

Note: The wooden toothpick should slide lengthwise (i.e., not roll) down the meter stick.

DATA ANALYSIS

1. Calculate the mean of the height for each object. Enter your result to data table.
2. Using your measurement data, calculate the standard deviation of the height for each object.
3. Calculate the relative error of your measurement of the height for each object.
4. Measure the mass of the coin, a wooden toothpick and a clothesbutton (in the internet find the mass of the object you are using).
5. Drawing and using the free-body diagram solution method, derive the equation for T for an object of mass m being slide an incline ($\theta > 0^\circ$) at a constant velocity. Set the coordinate system such that the x-axis is parallel to the incline.
6. Using the Pythagorean Theorem, the length of a meter stick and the measured height of the edge of the meter stick when each object just started to slide, calculate the base of the ramp for each object.
7. Using the result that the coefficient of friction at the angle of repose equals the ratio of the height of the ramp divided by the base of the ramp, calculate the coefficient of friction for the button, the coin and the wooden toothpick.
8. Find on the internet or in a library (e.g., the CRC Handbook of Chemistry and Physics) the ranges of coefficients of friction expected for wood on wood, plastic on wood, metal on wood (or vice versa).
9. Calculate the percent error of your experimental result.

PART TWO

We going to use the [online simulation](#) which represents two blocks connected by a string, where one block is located on the table and another block is hanging from the table. The simulation allows changing mass of each of the blocks as well as the coefficient of friction between the block and the table. Try various values for masses and friction coefficients (changing the “Type of Surfaces”), see what happens.

PROCEDURE DATA ANALYSIS

1. Change the mass of each of the blocks seven times.
2. Record your data on the Data Table.
3. For each combination of the mass change the coefficient of friction between the block and the table three times.
4. Record your data on the Data Table.
5. Consider the block being pulled horizontally at a constant velocity. Derive the equation of force, in terms of the following quantities: m , g , μ , θ .
6. Calculate the acceleration a as you change the mass of each of the blocks as well as the coefficient of friction how acceleration of the system changes as you change these variables.

7. From the Graph in the online simulation in your experiment determine f_{max} , f_k , and F_N .

