Sliding Friction*

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Friction is an inevitable phenomenon. Without friction, it would be impossible to walk or drive cars. However, friction is also the cause of energy loss and we would like to reduce it for higher efficiency in machines. In this experiment, we will study the force of friction as an object is stationary and in motion. We will calculate the coefficients of static and sliding friction using video motion analysis.

Essential pre-lab reading: "*Physics for Scientists and Engineers with Modern Physics; 3rd Edition*" by Fishbane, Gasiorowicz and Thornton; (Sections 5.1-5.6 and 6.1)

1 Test your understanding

1. What are the forces acting on a stationary body when it is placed on an inclined plane? Draw a free-body diagram and show all the forces.
2. Does the coefficient of sliding friction change when the angle of the incline is varied?
3. What are the forces acting on a body sliding down the inclined plane? Draw a free-body diagram and show all the forces.
4. Derive an expression for calculating the coefficient of kinetic friction in terms of acceleration and angle of incline. This expression will be used in the present experiment.

2 The Experiment

To measure the coefficient of static friction, a small block is placed on an incline plane. The angle of inclination is increased slowly until the block slips down. This specific angle is used to calculate the coefficient of static friction.

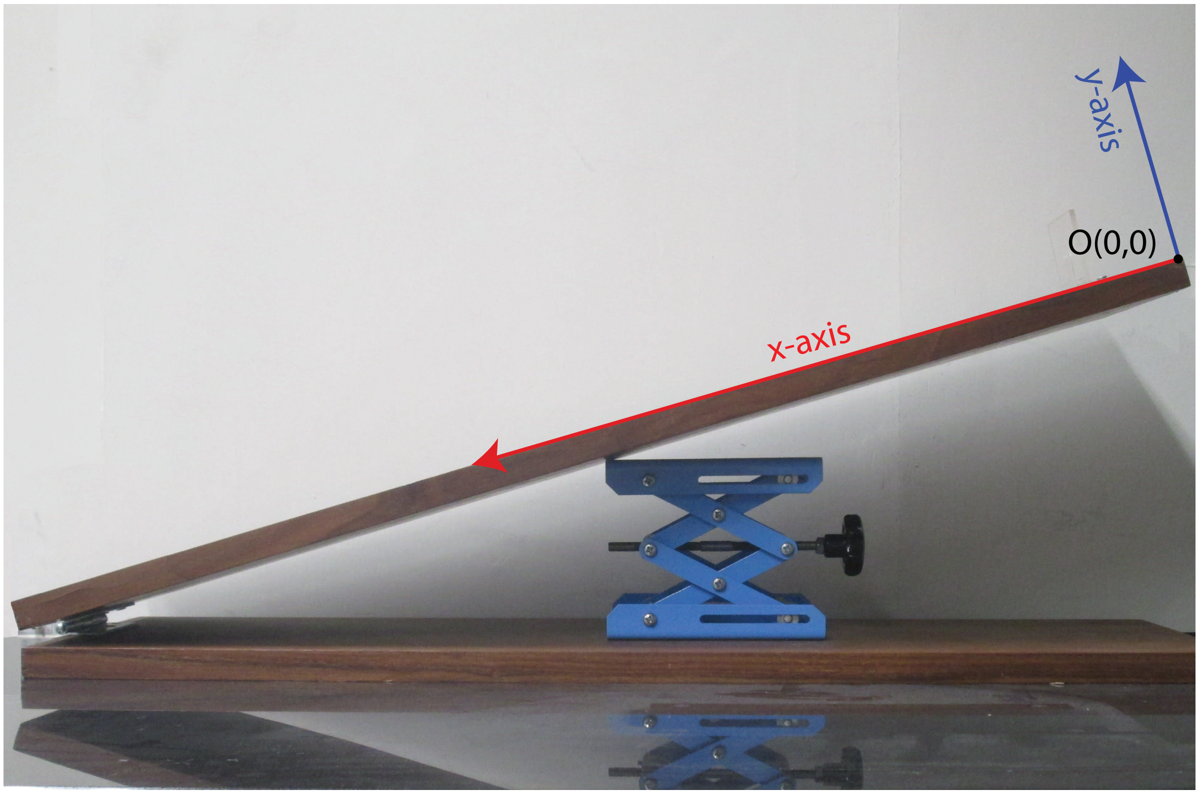

Figure 1: Set up for the measuring the coefficient of sliding friction. An appropriate choice for of coordinate frame is also shown.

To measure the coefficient of kinetic friction, the block is placed on the inclined plane. The block slips down the plane. A high frames per second (fps) video of the motion is captured and then analyzed using video tracking in MATLAB. Ensure that your set up looks like the one shown in Figure 1. Measure the mass of the selected sliding block prior to performing the experiment.

For video tracking, place the camera on a tripod and adjust the height until it is in-plane with the inclined surface. Move the tripod stand about 5-6 feet away from the set up and use the camera's optical zoom to fill the scene with the apparatus.

We will first measure the static, then sliding friction.

2.1 Measuring Static Friction

For the coefficient of static friction, first, reduce the inclination so that the block may not slip when placed on it freely. Place the block on the top of inclined plane and use the knob on the scissor-jack to increase the inclination. Keep on increasing the inclination slowly until the block slips down the plane. Calculate the angle at which the block has slipped. Repeat the process with the block placed on several different locations on the plane to find out an average value for the coefficient of static friction.

Q 1. How do you measure the angle of the incline?

Q 2. How can you use the angle of inclination to calculate the coefficient of static friction. Plot your results, showing the variation of static friction on different locations.

2.2 Sliding Friction

To measure kinetic or sliding friction, we will use the video motion tracking technique. Adjust the inclination of the inclined plane such that the block slips down right after it is placed on the surface.

After adjusting the inclination, note down the angle of incline in your notebook. Place and hold the block on the top of the inclined plane. With you partner's help, start the video recording and then release the block. If the block doesn't slip down, tap the plane gently to trigger sliding. Stop the video recording when the block has hit the bottom.

Adjust the inclination once again to a different angle and take another reading. Take as many readings as necessary.

3 Analysis

3.1 Video Analysis

Copy the videos to some appropriate location in the hard-drive. In MATLAB, browse to the video motion tracking library and run the script `fileInit` inside the object tracking directory. This will present an `open file dialogue`. Browse and select your video file. The script will automatically show a tool to trim the video. Use the `slider` and the `go-to buttons` to seek different frames of the video. Mark as `In-Frame` the moment when the object has just started to move and as `Out-Frame` the moment the object is about to leave the inclined plane. Preview the trimmed video and close the tool afterwards.

Once the file has been initialized, run the script `analyzeSlidingFriction`. Follow the on screen instructions to set up a coordinate system with x-axis parallel to the inclined plane and pointing downwards. When the script asks to mark the known distance, draw a line by clicking on two points with known real distance, followed by the key `enter`. When the script asks to mark the track point, drag and draw a tight rectangle around the marker you attached on the top of the sliding object.

Once the tracking is done, follow the on-screen instructions to filter out any stray points found in the tracking. If you are not satisfied with the tracking, choose to discard the trajectory when the script asks for it. The script will also ask to draw a line parallel to the inclined plane. This is used to cross check the inclination angle readings you have noted down in the notebook. At the end of a successful run, the script will leave the following variables in the workspace.

Physical Quantity	Variable Names
Linear displacement	d
`xdata` of the trajectory	dx
`ydata` of the trajectory	dy
Inclination of the plane	th
Time stamps	t

Table 1: Base workspace variables generated by the script.

Q 3. You will fit the position data to a model function. Write this function in your notebook.

Q 4. Will the y-components change with time? Why?

We now need to fit the processed data to a mathematical model. For this experiment a suitable model function is the general quadratic function which is given by

$$d = f(t) = a_0 + a_1 t + a_2 t^2. \tag{1}$$

Q 5. What do the coefficients a_0, a_1 and a_2 in Equation (1) represent?

Use the least-square curve fitting function `lsqfun3()` to fit the processed data to this model. The syntax for using this function is

```
model = 'a0 + a1 * t_ + a2 * t_^2';
fitResult = lsqfun(xData,yData, 'd', model , 't_');
```

The struct `fitResult` will contain the values of the unknown parameters.

Q 6. Use the model function above and the values of the three parameters to interpolate the time and position data.

Now, compute the first and second derivatives using `deriv` function to obtain velocity and acceleration. The syntax for using this function is

```
[xd, yd] = deriv(xdata, ydata, order)
```

where `order` is the required order of the derivative. Use 1 for computing a first-order derivative and 2 for a second-order derivative.

We now need to fit the velocity data to a mathematical model. For this experiment a suitable model function is given by

$$v = f(t) = b_0 + b_1 t. \tag{2}$$

Q 7. What do the coefficients b_0 and b_1 in Equation (2) represent?

Use the least-square curve fitting function `lsqfun3()` to fit the processed data to this model. The syntax for using this function is

```
model = 'b_0 + b_1 * t_;
fitResult = lsqfun(xData,yData, 'v', model , 't_');
```

Q 8. What is the value of acceleration down the incline?

Q 9. Use the value of acceleration to calculate the coefficient of sliding friction.

Q 10. Does the coefficient of sliding friction change by changing the inclination? What is the relation between these parameters?