SLIDING FRICTION & CONSERVATION OF ENERGY

Saddleback College Physics Department (adapted from PASCO Scientific)

Purpose:
Part I- To experimentally determine the coefficient of kinetic (sliding) friction, $\mu_k$, between a friction block (on which a Dynamics Cart will ride) and an aluminum track, and then use this value in part II of the experiment.
Part II- To use the principle of conservation of energy to predict the stopping distance, $D_{\text{pre}}$, of a friction block sliding down an inclined ramp and compare it with the measured stopping distance $D_{\text{mea}}$.

Apparatus:

![Apparatus Diagram](image1)

Figure 1
**Equipment:** two Dynamics Carts (ME-9430), ramp, end-stop (for ramp), plumb bob, meter stick, friction-block, stopwatch, lab jack (to elevate ramp), two 500 gram masses OR tape (to secure lower end of ramp if needed), table clamp as a stop (to prevent lower end of ramp from sliding)

**Theory:**

A Dynamics Cart will be launched down an inclined ramp, as shown in Figure 1 (cart on left), inverted on a friction block. _Hereafter the inverted cart with friction block system will be referred to as the “friction block”._ From the principle of conservation of energy we conclude that the initial elastic potential energy and gravitational potential energy of the cart are converted to thermal energy (i.e. work done against sliding friction) as the cart slides to a stop.

In _Part I_ of the experiment you will determine the coefficient of kinetic or “sliding” friction, $\mu_k$, for the friction block. In _Part II_ of the experiment you will use the value of $k$, the spring constant of the plunger, several other measured values and the principle of conservation of energy to predict $D_{pre}$, the distance the friction block slides after the launch cart’s (plunger bar) trigger is pushed. You will also measure the value of $D_{mea}$.

**Part I: Determining $\mu_k$**

If the angle of the ramp is high enough, the friction block will slide down the ramp with uniform acceleration due to a net force on the friction block. Let the angle $\phi$ be the angle of the ramp when the friction block slides down the ramp with uniform acceleration. The average acceleration down the ramp will be found using both Newton’s Laws and kinematics:

_(Include the steps below in your Theory for Part I)_

1. Draw a complete F.B.D. (Free-Body Diagram) of the friction block while it slides down the ramp inclined at the angle $\phi$.
2. Sum the forces on the block using Newton’s 1st and/or 2nd Law.
3. Solve your equations for the friction block’s acceleration (all in terms of variables) and write it in the box below.
4. CHECK with YOUR PROFESSOR to see that it is correct.

   $$a = \text{Eqn-1}$$

5. Now use a kinematics equation to determine the acceleration of the friction block, for Part I, in terms of the (average) total distance, $d$, the friction block slides (from rest) in an (average) time $t$. Write the equation for acceleration in the box below.

   $$a = \text{Eqn-2}$$
If the acceleration is uniform, Eqn-1 equals Eqn-2. You can use the measured value of the angle $\phi$ (the angle of uniform acceleration), the (avg) distance $d$ and the (avg) time $t$ to calculate the kinetic friction coefficient $\mu_k$. Solve Eqn-1 & Eqn-2 simultaneously for $\mu_k$ and write the result below in terms of variables.

Part II: Predicting D
The distance, $D_{\text{pre}}$, the friction block slides after the launch cart’s (plunger bar) trigger is released can be determined from the principle of conservation of energy. Let $x$ be the distance that the plunger is pushed in ($x = 2.80$ cm), $m$ be the total mass of the friction block (i.e. cart plus the friction block), $\theta$ be the angle of the ramp to the horizontal, $k$ be the spring constant of the plunger (630 N/m) and $\mu_k$ be the coefficient of kinetic or "sliding" friction calculated in Part I.

(Include the steps below in your Theory for Part II)
Work through the steps below. Let the initial position be when the launch cart’s (plunger bar) trigger is just pushed and the final position be when the friction block comes to rest:
1. Determine the change in gravitational potential energy of the friction block.
2. Determine the change in spring potential energy of the (launch cart’s) spring.
3. Determine the change in kinetic energy of the friction block.
4. Determine the work done against sliding friction in bringing the friction block to rest.
5. Apply conservation of energy to the friction block: $\Delta E = W_{\text{friction}}$, solve for $D_{\text{pre}}$ (predicted) and write it below.

Procedure:

NOTE: To get consistent results in this experiment, you must insure that the ramp you will be using is both straight (a non-constant acceleration of your block is a likely indication that the ramp is warped) and clean. Use the provided windex and rag for cleaning.

Part I: Determining $\mu_k$
1. Place the friction block on the ramp. Set up the ramp at a relatively low angle (one that does not cause the friction block to begin sliding down the ramp by itself).
2. Increase the angle of the ramp until the block will begin to slide down the ramp on its own, but only after you “release” it by slapping the table (or tapping the ramp very lightly). Now increase the angle of the ramp by a few more degrees so that the friction block will slide down the ramp with a uniform acceleration when you release it with a “slap” or tap. The angle of the ramp must be low enough so that the friction block does not begin to slide on its own -- only when you release it. **The most accurate way to determine the angle of the ramp is to measure any 2 sides of the right triangle formed by the ramp, the horizontal and the vertical. Use the plumb bob to determine vertical.** Calculate the angle of uniform acceleration ($\phi$ ) and record it in the data table.
3. Release the block from the grasp of static friction as described in the previous step and measure the time of the cart’s descent down the ramp. Record this time as $t$ in the data table below. Measure the distance $d$ that the block slides down the ramp and record this in the data table below. Repeat the measurements four times and average both $t$ and $d$.

Part II: Prediction of $D_{\text{pre}}$ and Measurement of $D_{\text{mea}}$
1. Now reduce the angle of the ramp slightly until the block will just barely slide down the ramp with a uniform speed when you release it with a slap or tap. Measure this “slip” angle. Reduce the angle of the ramp to about one half of the “slip” angle. Measure this new angle and record its value in the data section as \( \theta \) (you should have \( \theta < 10^\circ \)).

2. It is time to make a prediction – Using Eqn-4 and the information that you have recorded, predict \( D_{\text{pre}} \), the distance that the cart will slide down the ramp after being launched. Assume that the plunger on the cart is fully cocked at the position of maximum spring compression, \( x \). Record your prediction in the data table.

3. To maximize repeatability it is best to place the felted edges of the friction block in contact with the edge/lip opposite the measuring tape on the ramp for the decent.

4. To launch the friction-block cart down the ramp, place it below the launch-cart (with its plunger cocked in the maximum compression position) while the launch cart is secured or held at the upper end of the ramp, against the end-stop as indicated in Figure 1. To cock the spring plunger, push the plunger in (to the 3rd notch) and then push the plunger upward slightly to allow one of the notches on the plunger bar to “catch” on the edge of the small metal bar at the top of the hole.

5. Then tap the spring-release trigger with a rod or stick using a flat edge while the friction block remains stationary on its own. NOTE: You want to insure that you do not give the cart an initial velocity other than that supplied by the spring plunger.

6. To minimize any twisting motion, make sure the launch cart has a set of wheels over the edge of the ramp so that the center of mass of the launch cart and friction block cart both lie along the same line which is parallel to the ramp.

7. For six (or more, see NOTE below) trials, measure the distance \( D_{\text{mea}} \) that the cart slides and record these in the data table below. [NOTE: Periodically the plunger seems to catch upon release. You should be able to either hear this and/or conclude there was an error based upon your results. Use the best six trials in calculating your average \( D_{\text{mea}} \).]
Data:

**Part I**  \(d\) (avg) and \(t\) (avg)

<table>
<thead>
<tr>
<th>Trial</th>
<th>(d) (cm)</th>
<th>(t) (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td></td>
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<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>average</td>
<td></td>
<td></td>
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</tbody>
</table>

\[ \phi = \underline{\phantom{1}} \]

Spring constant, \(k = \underline{\phantom{1}} \)

\[ \mu_s = \underline{\phantom{1}} \]

**Part II** measured \(D\)

<table>
<thead>
<tr>
<th>Trial</th>
<th>(D_{mea}) (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<tr>
<td>2</td>
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<td>3</td>
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<td>4</td>
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<td>5</td>
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<tr>
<td>6</td>
<td></td>
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<tr>
<td>average (D_{mea})</td>
<td></td>
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</tbody>
</table>

\[ \theta = \underline{\phantom{1}} \]

Predicted value of \(D = \underline{\phantom{1}} \) cm
Analysis:

Part I:
Use Eqn-3 and the corresponding values to calculate the coefficient of kinetic or “sliding” friction. Enter it in the data table below.

Part II:
Calculate the average $D_{mea}$ value and compare (i.e. calculate % difference) it with $D_{pre}$.

Questions:
**Number your answers to the corresponding questions when listing them in your conclusion.**

1) In analyzing this system, has the energy been fully accounted for? Discuss.

2) Use energy conservation to calculate $v_1$, the speed of the friction block just as it loses contact with the launch cart. Show your work, writing the final equation all in terms of ALL variables.

3) Describe another way to use energy conservation to calculate $v_1$.

4) What if you launched the cart up the same ramp? How far up would it go?