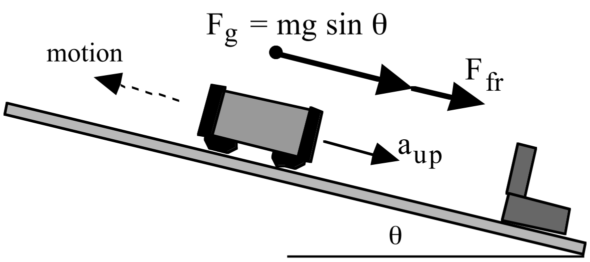
Cart on an Incline

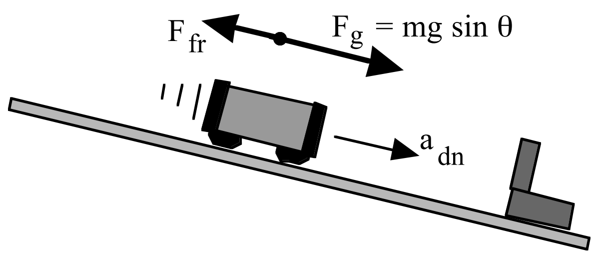
Theory:

As a laboratory cart goes up or down an inclined plane, it will be under the influence of two primary forces – gravity and friction. While it is comforting to consider only gravity, to fully understand the data one collects with a Motion Detector, you need to include friction in your work.

As the cart moves uphill (below left), the component of gravity and the friction force are both acting against the motion. This results in acceleration that we will call $\mathbf{a_{up}}$. This is the acceleration that slows the cart while it is going uphill. From Newton's Second Law of Motion: $\mathbf{F_{net} = ma = (F_g + F_{fr}) = m\, a_{up}}$.



Cart going up the incline



Cart going down the incline

As the cart moves downhill (above right), the component of gravity pulls it down while the friction force pulls uphill, working against its motion, resulting in $\mathbf{a_{dn}}$. Using the Second Law: $\mathbf{F_{net} = ma = (F_g - F_{fr}) = m\, a_{dn}}$. Note that absolute values of acceleration have been used in these two equations.

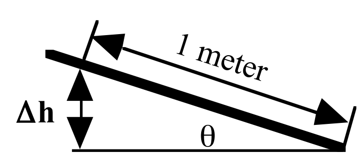
Purpose:

As you study the acceleration of a laboratory cart on an incline, you will use the motion of the cart to determine the angle of the incline and calculate the effective friction force acting on the cart.

Equipment:

Macintosh or PC Computer, Inclined Plane (ramp or dynamics track), Laboratory Cart, Meter Stick, Go! Motion or Motion Detector and LabPro.

Procedure:



1. Set up the inclined plane or dynamics track as shown above. Measure a length of 1 meter along the incline starting at the point where it touches the table. Measure the height from the table to the bottom of the incline at this point, **Δh**. Record this value in the Data Table. Measure and record the mass of your cart, **m**. Limit **Δh** to 5 cm maximum.
2. Connect the Motion Detector to your LabPro and place it near the bottom of the incline. With the LabPro connected to your computer, launch **Logger *Pro***. Open the file "06 Ball Toss" in the Physics with Computers folder.

3. Click on the "stopwatch" icon just to the left of the green Collect button. Change the duration of the experiment to 5 or 6 seconds.
4. Set the cart on the incline and practice pushing it uphill with just enough speed to rise near the top but not going over the edge. Be sure to catch the cart on its return before it crashes into the Motion Detector. (If your Motion Detector is green you can start the cart as close as 15 cm; but if it is blue you must start it about 50 cm from the Motion Detector.)
5. Initiate data collection by clicking the green Collect button. When clicks are heard coming from the Motion Detector, push the cart up the incline as you practiced. A good set of data will show smooth curves on both the position and velocity graphs.
6. When you have completed your analysis with one angle, repeat for a different angle if asked by your instructor.

Analysis:

1. Calculate the angle of the incline, $\boldsymbol{\theta_{trig}}$, from your Δh value. Note that Δh/(1 meter) is the sine of angle θ. (Both numerator and denominator have to be in the same units!)
2. Calculate the gravity force acting on the cart, **mg**.
3. On the velocity vs. time graph, determine the section where the cart is moving uphill. How did you decide this was the correct section to be examining? Determine the slope of this portion of the graph, which will be $\mathbf{a_{up}}$. Record this value.
4. On the velocity vs. time graph, determine the section where the cart is moving downhill. How did you decide this was the correct section to be examining? Determine the slope of this portion of the graph, which will be $\mathbf{a_{dn}}$. Record this value.
5. If you add the two equations given in the theory, you arrive at the following relationship:
$$\mathbf{2\ F_g = m\ (a_{up} + a_{dn})}$$
where $\mathbf{F_g = mg \sin \theta}$. Note that the equation assumes you are using absolute values of the accelerations, so drop any negative signs when doing this calculation. Now determine the angle of the incline, $\boldsymbol{\theta_{motion}}$, from your motion data.
6. Calculate the percentage difference between this value and the one you derived from using trigonometry and direct measurement.
7. If you subtract the two equations given in the theory, you arrive at the following relationship:
$$\mathbf{2\ F_{fr} = m\ (a_{up} - a_{dn})}$$
Determine the effective friction acting on the cart as it moved up and down the incline. If you divide the force of friction by $\mathbf{mg \cos \theta}$, you obtain the coefficient of friction, $\boldsymbol{\mu}$. Make a second determination of $\boldsymbol{\mu}$ and compare it with the value you obtained for the moving cart.

Discussion Points:

1. As you examine the velocity vs. time graph, what do you notice about the graph line as it crosses the horizontal axis where **v=0**?
2. Is your percentage difference in the two angles small enough to support the theory that was advanced at the beginning of this lab? What sources of error were there and how much would they likely have affected the results?
3. Do a quadratic curve fit for the position vs. time graph while the cart was going up the ramp. Compare the coefficients of this fit with the curve fit while the cart was going down the ramp. While you suspected the overall position vs. time graph was a parabola, it

really is two parabolas joined at the point where the velocity is zero and the friction force changes direction.

4. Do you expect the friction force to have a larger effect on the two accelerations if the angle is larger or smaller? Why? You can test this.
5. Does the mass of the cart have an affect on the accelerations? You can test this.
6. If you change carts to one with more or less friction, will the results you found still hold? You can test this.
7. How does the amount of friction you obtained in Analysis step 5 compare to the value you would have calculated after measuring the effective friction along a level track? You can test this.
8. Relate the results of this lab to the problem of stopping an automobile either going uphill or downhill.

Data Table:

Quantity	Symbol	Run 1	Run 2
1-meter incline Δ height	**Δh**		
Mass of cart	**m**		
Angle from trig.	**θ_{trig}**		
Gravity Force	**mg**		
Uphill acceleration	**a_{up}**		
Downhill acceleration	**a_{dn}**		
Angle from motion	**θ_{motion}**		
Percent Diff.	**%diff**		
Friction	**F_{fr}**		
Friction Coefficient	**μ**		
Second determination	**μ**		
Percent Diff.	**%diff**		

Note to Teachers:

Consider a performance-based assessment of this lab as follows: After allowing time to ask questions following the lab, hand the students a half-sheet of paper with two accelerations on it, one for going up the incline and one for going down. Ask them to tell you which one was the upward acceleration and which was the downward. Then have them tell you the angle of the incline. If they understood the lab well, they should be able to answer these two questions fairly quickly. And if they need to re-derive the equation, it isn't too difficult.

Consider this lab for a typical algebra-trig based college prep physics class. It can also be used effectively in an AP class.

Feel free to modify the items under Discussion to fit the needs of your students and your course as well as the time you wish to spend on this lab.

I believe this lab shows clearly why using technology can lead to deeper understanding of physical phenomena. We need to consider friction a real force that plays an ongoing part in our daily lives and we shouldn't just eliminate or ignore it when studying physical situations.

Clarence Bakken
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