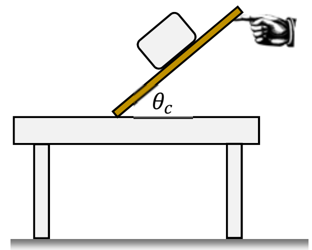
Static and Kinetic Friction

Apparatus: board, smart pulley, string, scissors, cleaning fluid, paper towels, hockey pucks with hooks, angle indicators, tape, table clamps, mass hangers with slotted mass sets, method for raising and lowering board (could be a human or a system of rods, bases and right angle clamps)

Goal: use various methods to compute static and kinetic coefficient friction coefficients

Project 1 – Get μ_s from θ_c

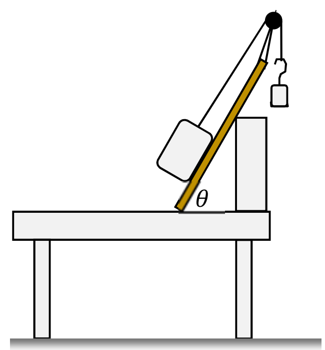


Start with the board horizontal. Place the puck on the board (handle puck by the edges). As *slowly* and *smoothly* as possible, raise the board. While you raise the board, monitor the angle indicator. At the instant the puck starts to slip, note the angle. The angle at which slipping occurs is called the critical angle (θ_c).

Using a slightly different location on the board for each trail, repeat this experiment for a total of ten trials to get an average value of θ_c. Use each value of θ_c to determine a value for μ_s between the puck and the board. Workbook problem **6.14** should be a big help. For *this* project, I do not care about seeing the FBD and force equations worked out in your submitted materials. You can use my results as long as you understand them. Note: after you have your ten values of μ_s we can do error analysis later…after Project 2.

Side note: in practice I've occasionally noticed an effect called *wringing* between the puck and the board. Due to this effect, you may observe critical angles significantly larger than 45° (giving $\mu_s > 1$). **Do not freak out!** Record the data and move on. To read more about wringing: https://en.wikipedia.org/wiki/Gauge_block#Wringing.

Project 2 – Get μ_s from largest hanging mass without slipping UP the plane
Start work for each new project on a new page



Now attach a string to the puck and run it over the smart pulley to a hanging mass as shown in the figure at right (not to scale). Your set-up should allow you to set the angle and leave the apparatus fixed at that angle for several minutes. To make life easier in later parts, please ensure the string is long enough for the puck to be placed as far from the pulley as possible. This allows us to use the entire board for a subsequent project.

Before taking data, verify the string is as parallel to board as possible.

Using $\theta = 40.0°$, determine the *minimum* mass required to cause the puck to slide *up* the incline. For convenience, everyone please call the puck m_1 and the hanging mass m_2.
I recommend using large masses (say 50-100 g) to first determine the approximate value of m_2 which cause the puck to slide upwards. Then take off some mass and go by smaller increments (say 20 g) to get a better approximation. Finally, go by 1 g increments to record your most precise value for m_2 that causes the onset of slipping. Don't spend all day, get a number and move on.

Repeat this experiement using $\mathbf{45.0°}$ and $\mathbf{50.0°}$. At this point you should know the minimum value of m_2 required to cause slipping *up* the plane for each of the three angles.

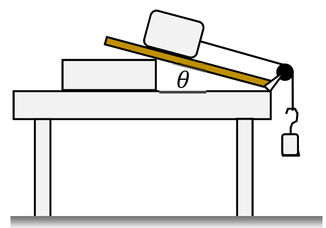
This project continues on the next page…

In your work for this project:

- Draw the FBDs for arbitrary angle θ
  - 1/4 page in size, well-labeled, subscripts on each mass
  - Assume up the plane is the positive x-direction
  - Rotate the coordinate system such that downwards is the positive x-direction for the hanging mass
  - Think: should the frictional force between the puck and the board point up or down the plane for this project? Which frictional condition aplies?
- Write out the force equations for each mass using the coordinate systems previously described
- Show algebraic work required to solve this set of equations for μ_s in terms of $m_1, m_2, \& \ \theta$
- Tabulate the data in Excel and use an Excel formula to generate values for μ_s for each angle used

Project 3 – Determine μ_k using FBDs, force equations, & vt-plots

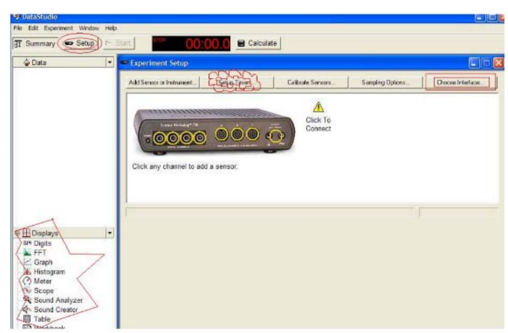
Consider the figure at right. Use trial and error to get a value for the hanging mass which causes the puck to slide for all $\theta \geq 0°$. For this experiment we want to use values of m_2 that are about 30-40% larger than the minimum value of m_2 required to cause slipping. Hint: if m_2 causes slipping at $\theta = 0°$, it should also cause slipping for $\theta > 0°$.



Tabulate data for a at each different angle θ in 5.0° increments from $\theta = 0 \rightarrow 30.0°$.
Hint: be careful when selecting to copy from Data Studio.
Ensure you only include data while the puck is sliding (plot the data to see determine times of release & impact).
To be clear, you should be using the same values for m_1 & m_2 for each angle.
You should be able to generate seven values of μ_k.

Before taking data, verify the string is as parallel to board as possible.

In this project, assume $m_1, m_2, g, \theta, \& \ a$ will be givens. Use *down* the plane as the positive direction. Draw large, well-labeled FBDs. Think about the direction of friction as well as the fricitonal condition which applies for this scenario (puck will be sliding down the plane). Determine force equations. Solve your force equations for the appropriate coefficient of friction. We will use this equation in an Excel spreadsheet…



Open Data studio on the lab computer.
Select "Create New Experiment".
You should see something like what is shown at right.
Look for a box near the computer which says "Science Wrokshop 750" on it.
This box is called the interface.
Very the interface is plugged in, turned on, and connected to the computer.
Connect the cable from the smart pulley to the interface.
On the computer screen, clikc on the input where the pulley is connected.
A drop down box should appear, look for "Smart Pulley".
We want to make plots of velocity versus time.
Your instructor can help you at this point to get that data in tabular form on screen.
From there, you can cut and paste the data from Data Studio to Excel.
Once the data is in Excel, you can use Excel to determine acceleration from the slope of the vt-data (hint: use the SLOPE command in Excel.

Continues on the next page…

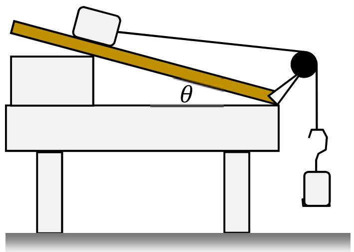
Error analysis

You are also expected to determine a value for the uncertainty in your values of μ_s for each of the previous projects. At this point you should have 10 values of μ_s from **Project 1** and 3 values of μ_s from **Project 2**. You should have seven values of μ_k from project 3.

The techniques for determining errors are described in bullets 2a & 2b of the following link: http://www.robjorstad.com/BriefErrorAnalysis.pdf

The easiest way to do this is in all experiments is to use tabulate raw data in Excel, use FBD's and force equations to create equations for computing μ_s or μ_k, then get the average and standard deviation. Side note: I believe Excel has updated the STDEV function to STDEV.S.

Conclusion Questions



1) Suppose the string was not perfectly parallel to the plane in **Project 3**. For example, suppose the angle of the string looked more like what is shown in the figure at right (angled *slightly* above the plane of the incline). How are each of the following affected? State if the parameter increases, decreases, or stays the same AND explain your reasoning. If no reasoning is provided, no points.
   a. normal force
   b. component of m_1's weight directed down the incline
   c. fricitonal *coefficient*
   d. frictional *force*
2) Let us assume we know a quality value of μ_s from **Project 1**.
   In **Project 2** you found the minimum value for m_2 which causes slipping up the plane.
   Let us call this value m_{2min}.
   Use your value of μ_s from **Project 1** to determine the *angle* in **Project 2** which maximizes m_{2min}.
   Think: by now you should realize m_{2min} depends on $\theta, m_1,$ & μ_s.
   You should be able determine which angle gives the largest possible value of m_{2min}.
   Hint: some problems are best solved *numerically* instead of *analytically* (using algebra &/or calculus).

Turn in Checklist is on the next page…

Turn-in checklist:
Use plain white or engineering paper for all work.
Use one side of the paper for all work.
In the upper right hand corner of the first page I expect the following:

- your full name listed (denoted as author)
- your partners full names
- your lab meeting time

Staple your final packet in the top left corner.

Notes for each project should start on a new page, regardless of how much blank space this causes.
FBD's should be large and well labeled (using subscripts to distinguish masses as appropriate).
For two block problems is sensible to put the two FBDs side by side with force equations shown beneath.
Coordinate systems should be included (use the ones described in this handout).
Algebra should be clear and easy to follow

- Work down the page, not left to right
- If you run out of room, start a new page (regardless of how much blank space this causes)

You can print out a data table from Excel and share it as a group (give each student a copy).

- Format the table well (units, sig figs, proper subscripts, italics, include borders around each data table)
    - *Italics* should be used for *variables* (but not for numerical subscripts)
    - Units are not italicized
    - Do NOT include the vt-data…it would waste too much paper.
- **Hit print preview before wasting tons of paper!** Improve your table layout before printing.

Everything else must be individually hand-written.

You are expected to do most calculations in Excel and have the computer do the work for you.
Exception: Include a single sample calculation of μ_k (calculate one value by hand).
This sample calculation should show the following:

- The algebraic equation
- The numbers plugged in without any simplification or math done
- One intermediate step (showing simplified numerator and denominator, with sig figs indicated)
- Unrounded final answer (with appropriate units)
- Rounded final answer (with appropriate units)

Include the data table *after* the handwritten work for all three projects.

Include the conclusion questions after the data table.
Answer these questions using full sentences which make clear what question was asked.
Include the rationale behind your answers for credit.