1. You may have noticed already that friction depends in some way on the force that holds one of the the rubbing objects in contact with the other. In #3 on page 38 that force was exerted on the block by the _________, in the ____ward direction. Since that force must be perpendicular to the sliding surfaces, it is called a **normal force.** (The Latin word for a carpenter's square is "normalis".)
   a. Forces come in pairs: If "A" exerts a normal force on "B", then B must exert a normal force on __.
   b. Those two normal forces must have _____ strengths and _______ directions, as in #2 on RS III.
   * c. Describe a *general procedure* for measuring the normal force exerted on an object such as an eraser by a surface such as a blackboard. Remember to mention the *direction* of that force.
   d. Does your method for measuring normal forces always work? For example, can you use the same technique to measure the normal force exerted by the counter on the wood block in your previous friction experiments, and will it work in an accelerating elevator? ___ *If not, please rewrite it.*

2. Imagine dragging an object uphill, with constant velocity:
   a. According to #3 on RS III, the object's acceleration is ____ , *because* the total force on it is ____.
   b. Draw and label a vector diagram showing how the four forces acting on the object are added "tail-to-head". *Remember: "normal" means __________ to the surface, and **mg** is always ____ward.*
   c. The diagram clearly shows that the uphill force is ______ than the friction force in this case, and that the normal force is _____ ____ the object's weight. (less than, equal to, greater than)

3. Find out how friction *depends* on normal force. Make two graphs: one for sliding friction *force,* and one for static friction *limit.* This investigation will be simplest if the surface is _______. (level, tilted, vertical) The propelling force should be ________al, and the speed should be _________. You can adjust the normal force by loading the blocks with heavy objects.
   a. Make graphs *while the experiment is in progress.* Make your measurements as precisely as possible and record uncertainty estimates at the bottom of each column in your data table.
   Use standard force units for all of your measurements, including the normal force.
   b. Plot each data point immediately. Then have your partner repeat the measurement and plot it *again*.
   c. On the same paper, write equations describing the graphs. (Express the sliding friction *force* and the static friction *limit* in terms of the normal force and constants.) *Use symbols, not numbers.*
   d. Define those symbols. -Copies of those equations have been recorded in # ___ & ___ on RS ___.

4. The slope of such a graph is called a "friction coefficient". Don't contradict #3:
   a. A "sliding friction coefficient" must be the slope of a _______ _______ force vs _____ force graph.
   b. A "static" friction coefficient must be the ____of a _____ _____ _____ vs ______ _______ graph.
   c. Have you saved copies of those definitions and sketches of the graphs on RS III? ___
   * d. Use your graphs to determine the static and sliding friction coefficients in *range* form. Write them *on* the graphs, near the equations. Use #10 on RS I. Be sure that there are straight lines drawn from the origins on your graphs. *Those lines must fit the data reasonably well, and must have slopes equal to the SLV and GLV of the friction coefficients.* Which coefficient is greater? _______
   * *If you claim they are exactly equal then explain how you measured them with perfect precision.*

5. Is it possible to pull on the block with a force that exceeds the static friction limit but is less than the sliding friction force? ___ If so, explain which way the block will accelerate, and why. If not, explain what this tells you about 4d. (Use inequality language.)

6. Are all friction coefficients equal? ____ Do different materials have different coefficients? ______
   -Would you get the same coefficients if you used a different force unit? _____

* 7. Do you think the equations in 3c *might* correctly describe the behavior of the "rolling friction" experienced by skateboard wheels? State those equations clearly and give a reason for your opinion.

8 How much horizontal force is needed to drag a 4.0-kg block of concrete along a horizontal floor at a constant velocity of 1.5 m/sec if the friction coefficient is 0.21? (Use the space below to *show* how the *given* information is used to obtain your answer. If you neglect to use #8 on RS III, I'll scream!)

9. A 3.5-kilogram sled carrying a 30-kilogram boy can be dragged with a 20-newton forward force on a frozen lake at a steady velocity of 2.3 m/sec eastward.
   a. Show how you use the *given data* to calculate the friction coefficient.
   b. How much force is needed to drag it at twice the former speed? Use #18 on RS III or #10 on RS II.

1. To put your data into the calculator: Hit the STAT key, then ENTER to get into "edit" mode, so that you can see a data table. (If you need to clear old data out of the "L1" column, move the cursor to the column heading, hit CLEAR, then ENTER. Do the same for the L2 column if necessary.)
   a. Type your *normal forces* into the L1 column.
   b. Put the corresponding *friction forces* into the L2 column of the data table.

2. To prevent old equations from being graphed on-screen: Hit the **Y =** key. If you see any equations listed on the screen with their "equal" signs highlighted then you must remove them with the CLEAR key *or* switch them off (so their graphs won't be displayed) by putting the cursor on the **=** sign and hitting ENTER. (An equation's graph will be displayed only if the = sign is highlighted.)

3. To select the type of graph you wish to display:
   a. Hit 2ND, STATPLOT, ENTER.
   b. Select "ON", and hit ENTER to switch on "plot #1" so it will be displayed.
   c. Select either the first or second type of graph, hit ENTER again.
   d. Select L1 for the X-LIST, so that the *normal force* will be on the *horizontal* axis.
   e. Select L2 for the Y-LIST, so that *friction* will be on the *vertical* axis.

4. To choose appropriate scales for your graph:
   a. Hit the ZOOM key, and select choice 9 (zoom stat) to scale the graph automatically.
      Then ENTER.
   b. Then hit the WINDOW key. Change the XMIN and YMIN values to zero, so the origin will be visible on your graph. To see your graph displayed on the screen, hit the GRAPH key.

5. You should be familiar with a simple equation which has a similar graph.
   Let's draw the graph of that equation onto the screen to see how well it fits your data points:
   a. Hit the Y= key. Enter the equation that you had in mind. Then hit the GRAPH key.
   b. Hit the Y= key again and alter your equation in some way. (Try to make it fit a little better.)
   c. By trial and error make *two* such equations, so that there are two straight lines on the graph, both fitting your data points reasonably well. According to the Olympic Rule, two-thirds of your data points should be between those two lines. Show the results to your teacher.

6. Sketch the graph (including the dots and lines) on a piece of paper.
   Give it a title and label the axes clearly.

7. Write a *conclusion* beside your sketch. That means:
   a. Write an equation describing the graph, using standard abbreviations or letters.
   b. Define those letters or abbreviations clearly.
   c. Give the numerical value of the proportionality constant in *range* form.