LAB 1 INERTIAL MASS

EXPERIMENTAL GOAL

According to chapter C3, an object's mass m is a quantity that expresses how strongly it resists changes in its motion. However, an object's mass also seems to express how strongly the object interacts with the earth: the force that the object's gravitational interaction with the earth exerts on the object is $\vec{F}_g = m\vec{g}$, where $\vec{g}$ is the earth's gravitational field vector. Why should a quantity expressing an object's resistance to changes in its motion (which we will call its **inertial mass**) have anything whatsoever to do with the quantity that expresses the strength of its response to the earth's gravitational field (which we will call its **gravitational mass**)? In fact, since this issue was first recognized as an interesting question in the late 1800s, a number of experiments have been done to check that these quantities really are equivalent. (One of the great successes of the theory of general relativity is that it offers a simple explanation for why these quantities are linked.)

In this lab, you will check to see whether a block of wood and an iron rod having the same gravitational mass (according to a pan balance) also have the same resistance to changes in their motion (by seeing how long it takes a spring to shake the objects horizontally back and forth). As we will see in unit Q, all atoms have a somewhat smaller gravitational mass than the sum of the gravitational masses of the protons, neutrons, and electrons that go into them. This discrepency is significantly greater for iron (which has the most tightly-bound nucleus known) than it is for the hydrogen, carbon, oxygen, or nitrogen atoms that comprise the majority of the atoms in a block of wood. Therefore, if there is a difference between inertial and gravitational mass, we might reasonably expect it to show up if we compare wood to iron.

LABORATORY SKILLS you will be developing:

In addition to exploring this interesting experimental question, the main *educational* purpose of this lab is to learn about how to handle experimental uncertainties. We will be returning to the data we collect in this lab later as we develop more sophisticated data analysis tools.

SOME PROCEDURAL SUGGESTIONS AND NOTES

Since this is the first lab in the semester, we will describe the procedure in some detail (later, you will play a greater role in designing your procedure).

1. We will pass around a pan balance. Carefully compare the gravitational mass of your block of wood and your iron rod (with its foam disks to verify that they are the same within the uncertainty of the scale. If they are not, talk to your helper about how you might adjust the masses so that they are equal. (While you are waiting for the scale, you can decide who in your team will be responsible for the various roles, practice step 2, or work on step 4.)
2. Place the iron rod *gently* into the plastic cylinder and close the cylinder with the cap. Pull the cylinder horizontally until it just barely touches the horizontal bar, and then release it. Use the stopwatch to measure how long it takes the cylinder to oscillate horizontally exactly 5 times. Each person on your team should take 20 measurements of this time. You might practice this a few times to get used to the stopwatch before officially starting to record measurements.
3. Open the cylinder, pull out the rod, *gently* slide in the wooden block, and close the cylinder again. The plastic cylinder is not perfectly round, so you may have to turn the block around its vertical axis to find the orientation where it slides easily into the cylinder. It is very important when you change items that you put as little vertical pressure on the steel springs as possible. Again, pull the cylinder horizontally until it just barely touches the horizontal bar, and then release it. Use the stopwatch to measure how long it takes the cylinder to oscillate horizontally exactly 5 times now. Again, each person should measure this time period 20 times.
4. The basic assumption of this experiment is that object with *different* interial masses will have different oscillation periods when placed in the cylinder. Think of a way to check that this assumption is true, describe your idea to your helper, and then carry out your test.

5. At the end of step 3, each *person* will have 20 time measurements for oscillating iron and 20 time measurements for oscillating wood. According to your test in step 4, these times will be the same if and only if the two objects have the same inertial mass. Divide the first iron time by the first wood time to get a unitless ratio that will be close to one. Repeat for your second iron and wood measurements, your third, and so on. Make sure that you can explain to your grader (a) what you would *expect* this ratio to be if inertial mass is really equivalent to gravitational mass and why, and (b) why your ratios differ from this expected ratio.

6. Read chapters 2 and 3 in the *Lab Reference Manual,* and do the exercises for those chapters (you will show your work to the grader eventually). Calculate the standard deviation of each of your sets of 20 ratios and the uncertainty range of your 20 ratios. What can you conclude (if anything) about the “true” value of this ratio? Is your expected ratio within your uncertainty range? Make a histogram of your 20 ratios. Does it look like a bell curve?

7. Provide a list of your team’s ratios and standard deviations to a lab assistant. These ratios will be put in a spreadsheet that at the end of the week will contain ratios collected from the entire class (roughly 1200 measurements!). We will discuss the complete class results at the beginning of next week’s lab.

8. This experiment was carefully designed to eliminate possible systematic effects. Discuss the following questions about the experimental design in your team and with your helper, and be prepared to offer thoughtful answers when asked these questions by your grader.

   (a) Why do we put the objects inside the capped plastic cylinder?

   (b) Why does the iron rod have foam rings?

   (c) It would have been simpler to hang the objects from a spring and let them oscillate vertically instead of horizontally. Why didn’t we do this?

   (d) Why did we ask you to pull the cylinder so that it just touches the horizontal rod before releasing it?

9. When you think that you completely understand the lab and are prepared to answer all questions about it (and have completed work on the exercises in chapters 2 and 3), ask your grader for a checkout interview.