Lab 2: Conservation of Momentum

I. Before you come to lab...
A. Read through this handout in its entirety.
B. Reread through the handout on error propagation.
C. In Logger Pro, do the Tutorial named 12 Video Analysis (in the Tutorials folder under Experiments).
D. Watch the following YouTube video on the Gauss gun (there's also a link from the course website):
   http://www.youtube.com/watch?v=zZmCJ5eZlmo

II. Background
A. Rounding and significant figures
   1. A little boy and his mother walk into the natural history museum and see a huge dinosaur skeleton in the lobby. "Wow!" says the boy. "I wonder how old those bones are?"
      A nearby security guard answers, "That skeleton is 90,000,006 years old!"
      "90 million and six? Are you sure?" asks the boy's mother.
      "Course I am," replies the security guard. "I asked the curator how old it was when I started working here, and he said 90 million years. And I've been working here for six years."
   2. Okay, it's a silly joke, but it gives us pause for thought. What's wrong with the security guard's answer? The uncertainty in the age of the skeleton is on the order of millions or tens of millions of years. So it's preposterous to make any claims as to the ones digit; the six years don't matter in the least. Even if we don't necessarily quote uncertainties when tossing numbers around in everyday conversation, it's still absurd to make such a huge error in the number of significant figures.
   3. Arguably, it's even more absurd to make such an error when you are, in fact, quoting the uncertainty along with the value. For example, on lab reports in the past, students have made claims such as:
      "We measured a value of 1.4969461 ± 0.27777777." If the uncertainty in the value was about 0.28, why would you claim to know the result to seven decimal places? Maybe because that's what your calculator said when you plugged in the numbers? Don't believe everything that your calculator tells you! Your calculator is dumb, and you are smart. Your calculator can only push numbers around; you have the mental capacity to understand what the numbers mean—and what they don't mean. In this case, no matter what your calculator says, you know full well that you have zero knowledge of even the hundredths digit of the answer, and only partial knowledge of the tenths digit.
   4. Here's a rule of thumb you can rely on: round the uncertainty to one significant figure. Then round the answer to match the decimal place of the uncertainty. In our example above, we would just say that the uncertainty is 0.3, and the actual value would be rounded to the nearest tenth in accordance with the uncertainty. So the final result would be:
      "We measured a value of 1.5 ± 0.3."
      If the uncertainty were only 0.00277777, we'd call it 0.003 and the result would be 1.497 ± 0.003. The small uncertainty gives us confidence that the thousandths digit is meaningful.
   5. One exception to the rule of thumb: If rounding the uncertainty to one significant figure would cause that figure to be a 1, then you can keep the next digit as well. So for instance, if you have 5.83333333 ± 0.14285714, then you would round the uncertainty to 0.14 (instead of just 0.1) and report 5.83 ± 0.14 (instead of 5.8 ± 0.1).

B. Error propagation: see handout

III. Introduction
A. Scientists are rarely given explicit procedures when they walk into their labs every morning. They have a problem they want to solve and possess a figurative toolbox of concepts, equations, and techniques, in addition to an actual toolbox of available equipment, to help them do so. They will determine what phenomena to investigate, what
values to measure, and design an appropriate procedure—an experiment—to follow in the lab.

B. With this in mind, you will need to design a procedure for this lab. You will explore the conservation of momentum in an interesting physical system: the Gauss gun. As you saw in lecture and in the online videos, the Gauss gun can be used to shoot steel ball bearings at high speeds. The details are complicated because they involve magnetic forces, which we won’t cover in this course. However, the beauty of momentum conservation is that we don’t have to know or care about the details of the interaction: we just look at the initial momentum and the final momentum and compare them. You will design an experiment to answer the question: “Is momentum conserved during the firing of the Gauss gun?”

C. Objectives for this lab:
1. Investigate momentum conservation by designing your own experimental procedure

IV. Materials
A. Magnet, 3 steel ball bearings, and some track
1. What they are: a magnet, 3 steel ball bearings, and some pieces of track.
2. What you can do with them: make a Gauss gun! Check this out:

http://physci.fas.harvard.edu/~french/PS2/Lab2/gaussgun.mov

B. Sandbox and rake
1. What they are: a small box filled with sand and a rake.
2. What you can do with them: If you drop something into a well-raked sandbox, it’ll leave a mark in the sand at the spot where it landed...which could be useful.

C. 2-meter stick
1. What it is: like a meterstick, except twice as long.
2. What you can do with it: measure lengths up to 2 m.

D. Digital video camera on tripod
1. What it is: pretty sweet.
2. What you can do with it: record video of something at 30 frames per second. Then, you can analyze the motion of objects in the video every which way using Logger Pro’s video analysis capabilities.

E. Lubricant
1. What it is: slippery.
2. What you can do with it: reduce sliding friction by applying a small amount of it to the track.

F. Level
1. What it is: a carpenter’s level.
2. What you can do with it: make sure that a surface is really horizontal. If it’s not, you can shim one side or the other with pieces of paper.

G. Balance
1. What it is: a digital balance.
2. What you can do with it: measure the mass of small objects.
   a. The balances read to the nearest hundredth of a gram. That means that when you measure a mass using
      the balance, the reading error on the mass is 0.01 g.
   b. If you use the balance to measure the mass of a magnet, you might get an inaccurate reading because of
      an attractive force between the magnet and the metal inside the balance. To get an accurate measurement,
      put an inverted plastic cup on top of the balance and re-zero it before putting the magnet on top. That way
      the magnet will be several inches away from anything metal while it is being weighed.

H. Computer with Logger Pro installed on it
   1. What it is: what it sounds like.
   2. What can you do with it: data collection and analysis.

V. Procedure
A. Before you begin:
   1. Take a picture of yourselves using Photo Booth and drag it into the space below:

   2. Tell us your names (from left to right according to the above photo):

B. By the time you enter the lab, you should have an explicit procedure from your pre-lab assignment. Compare
   and contrast your ideas with your labmates for no more than 5-10 minutes and agree on a procedure. It
   behooves you to finalize your procedure quickly so that you have enough time to take data. Before beginning talk
   to your TF to make sure (s)he has any helpful advice.

   Things to keep in mind while writing your procedure and performing your experiment:
   1. Since you are trying to answer the question "Is momentum conserved?", you will need to keep track of
      uncertainties for all of your measurements.
   2. You need to come up with a plan to measure and/or account for friction in some way. NOTE: Dousing the
      track in oil is not a valid explanation/solution.
   3. Occasionally, when the balls collide with the magnet, there is a lot of "extra" movement in directions other than
      along the length of the track. This will result in the magnet and balls wobbling back and forth and can lead to a
      very bad measurement. If this happens to you, just repeat the experiment instead of spending a lot of time
      analyzing bad data.
   4. The camera's field of view is only so big. When setting up the camera, think about what needs to be on
      camera.
   C. Use this space to write out your procedure. Be sure to clearly explain what you intend to measure and how.
      BE EXPLICIT!
   D. Use this space (and below) to record your measurements, observations, data, graphs, and analysis.
      Include all of your work. Insert as many cells as you want. Remember <return> makes a new box and
      <apple-return> makes a new line within a box.
   E. On your problem set this week you will see if momentum was conserved within your uncertainty.

VI. Conclusion
A. Submit your lab report online according to the instructions on the plastic sheet at your computer.
B. Super-duper important—don’t even think about skipping this step! Before you leave the lab, every member
   of your lab group should open a browser and go to
   http://physci.fas.harvard.edu/~yourFASusername
   and make sure that your lab report is there under the link called "Lab 2." If not, then you haven’t submitted it
   correctly; ask a TF for help. If your lab report isn’t submitted, you won’t get credit for doing the lab.
VII. Pre-lab assignment from the Problem Set

A. These questions are here for reference.

B. In Logger Pro, do the Tutorial named 12 Video Analysis (in the Tutorials folder under Experiments).

C. Design a procedure to determine whether momentum is conserved in the operation of the Gauss gun. You'll need it at the beginning of the lab. Make sure you make two copies—one to hand in with HW #2, the other to bring with you to lab. Some things to think about when designing a procedure:

1. You'll be given the equipment listed above, but thinking outside the box is encouraged. If you want to use something not listed, email Tim before you come to lab and if it's practical, we'll try to make it happen.

2. It's a good idea to know exactly what you plan on doing before you step foot in the lab. You have the full three-hour period, but experiments don't necessarily (or usually) work the first time they are done. Make sure you are well organized and well prepared for lab and be as explicit as possible in your procedure.

3. Checking momentum conservation involves comparing an initial momentum to a final momentum. That means you should think about what state you'll consider to be "initial" in your experiment and what state you'll consider as "final."

4. Remember that to make any statement like "momentum was conserved" or "momentum wasn't conserved," you need to determine not only the initial and final momentum, but also the uncertainties that go with them. This might involve keeping track of a whole lot of uncertainties and doing some serious error propagation. Therefore, it means that you should be able to estimate the uncertainty of any measurement you make (e.g., through reading error, etc.).