Making a Mass Spectrometer

The mass spectrometer described here is supposed to be direct analog of "real" mass spectrometers used for analysis of real atoms and molecules. Almost every "real" mass spectrometer has five major systems: (1) introduction of sample, vaporization, and ionization; (2) acceleration of the ions to a known kinetic energy; (3) generation of different trajectories for ions with differing ratios of mass to charge, (4) detection of the ions and associated read-out electronics, and (5) a vacuum system so that the trajectories are not disturbed by collisions with other molecules. For our purposes, subsystems (2) and (3) are the most important. In (2) the particles are accelerated to the same kinetic energy, regardless of their mass, and in (3) the particles with differing masses acquire differing trajectories. In the mass spectrometer described here, the foam atoms are accelerated to the same kinetic energy, regardless of their mass, by the contraction of the elastic, and the differing trajectories are set by the movement of the foam atom in response to gravity. Further explanation of the physics is given here.

Materials/Equipment Required

10 foot long piece of ¾" ID (heavy wall) PVC tubing [Hint: Smaller tubing could work, but it seems too flexible for this application.]
6 tees for ¾" PVC tubing [Hint: always check to see that your tees fits on your tubing]
glue sticks (multi-heat)
jumbo size metal paper clips, about 1 7/8" long, (minimum 3, probably more)
small metal paper clips, about 1 ¼" long, (minimum 2, probably more)
6 feet of braided (sewing) elastic, 1/8" wide (I used Walmart Stretchrite 3182W, but other sources are fine.)
heavy rubber bands (2)
light string (2 feet)
needle nose pliers
PVC tubing cutter (You can cut PVC tubing with a saw, but there will be chips and sharp edges; spend $10 and get a PVC cutter if you are going to cut PVC regularly.)
glue gun (high heat) [If you made foams atoms, you already have a glue gun.]
one old manila folder
scissors

Figure 1: PVC tubing cutter, needle nose pliers, and glue gun.

Instructions

1. Cut the PVC tubing as follows:
   A: 2 lengths, each 2 ½ feet long
   B: 2 lengths, each 1 foot long
   C: 4 lengths, each 8 inches long
   D: 2 lengths, each 2 inches long

The exact dimensions are not important, but the pieces in each category above should be close in length.

2. The assembled MS is shown in figure 2 and figure 3. DO NOT GLUE the joints. You want to be able disassemble the frame for storage and gluing is not required for successful operation of the MS. The frame can hang over the edge of a table as shown in figure 2.

Figure 2: Assembled MS

Figure 3: Assembled MS

3. Cut two lengths of elastic, each approximately 2 feet long, and tie a loop in one end [the loop should be tight on the PVC tubing.] Slip the loop end over the PVC tubing as shown in figures 2 and 3. Use the heavy rubber bands to secure the elastic so that it cannot move along the PVC tubing while the MS is in use. [Note: it matters a bit just how far up the PVC tube the elastic loop is placed. It certainly needs to be high enough for the foam atom, as it is launched, to clear the end of the MS apparatus. See the physics discussion for further understanding.]

There is a bit of judgment call here – the longer the length of the elastic, the smaller the force for a given extension of the elastic, and the easier it is for students to use the MS reproducibly. If you seem to be having too much force for too small an extension, use longer elastic pieces. This problem also arises if the elastic is too wide or too “strong”.

Tie the other ends of the elastic through the small paper clip. Pay attention to the orientation of the paper clip. The end shown in red in figure 4 will be toward the cradle. Tie the elastic to the silver end.

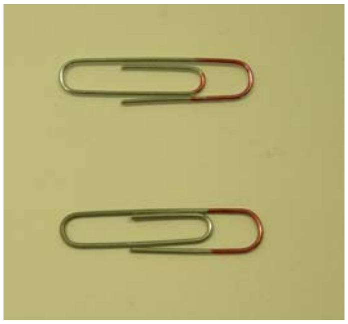

Figure 4: Small paper clips

4. Now comes the most difficult part, making the cradle for the foam atom. Use the needle nose pliers to bend a jumbo paper clip, shown before bending in figure 5 and after bending in figure 6. Glue the side strips – shown in red in figure 7 – together.

Figure 5: Large paper clip

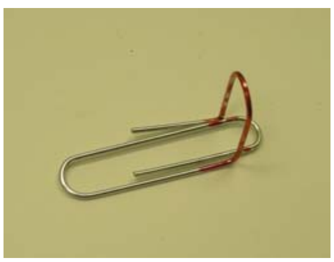

Figure 6: Large paper clip after bending

Figure 7: Sides to be glued

5. Cut a piece of the manila folder ¾" wide and 3" long. Mark the strip ½" from one end. Gently roll the strip over a curved object – a magic marker worked fine for me – so that it becomes curve without creasing. Bend the strip into a cylinder so that the inner diameter is exactly 2 ½" [Aha! One end is at the ½" mark you made previously.] and glue the tab down. Glue the cylinder onto the jumbo paper clip as shown in figure 8.

Figure 8: Bent clip with paper cylinder

6. The completed cradle is shown in figure 9. Glue a jumbo paper clip on to the end of the cradle as a handle. Use a nice size lump of glue and make sure that the plane of the handle paper clip is perpendicular to the plane of the cradle paper clip. Insert the small paper clips – tied to the elastic – into the cradle jumbo paper clip as shown in figure 9.

Figure 9: Completed cradle

7. Tie one end of a piece of string through a jumbo paper clip and slip the paper clip onto one of the MS base pieces, as shown in figure 10. Tie the other end of the string to the handle paper clip.

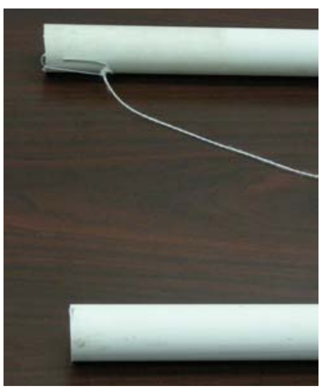

Figure 10: Attachment of string to MS frame

How long should the string be? The purpose of this string is to stop the motion of the cradle assembly and allow the foam atom to separate cleanly from the cradle. Extend the elastic to its full unstressed length. There should be about 2” slack – more or less -- in the string at this point.

Using the Mass Spectrometer

1. The basics are simple – load a foam atom into the cylinder into the cradle cylinder, pull back on the handle paper clip, and let go. The elastic contracts, the foam atom flies, and you are in business. Measure where it hits the floor, find it, reload, and have more fun.

Now let's talk about reproducibility and scientific measurements.

2. Students will need to learn to use the MS carefully in order to acquire reproducible measurements. Have them work with just one atom until they get pretty good with the apparatus.

3. They will need to hold the handle carefully (in a vertical plane) and release it reproducibly.

4. They will need to have a method for extending the elastic the same amount each time. Not hard to do, but it takes some thought at first.

5. They will need to have a method for measuring how far the foam atoms go, and for determining the reproducibility of the trajectories. Consider placing a small piece of masking tape (labeled) at the point where the foam atom hits the floor.

6. It is OK not to be perfect at first. Real scientists build an apparatus, try to use it and find that it does not work as projected. They think about the goals and results, modify the apparatus and/or their techniques for using the apparatus, and try again. And again. And again.

Suppliers

(I have no financial interest in any of the suppliers mentioned.)

PVC tubing, PVC tubing cutter, needle nose pliers – any hardware store. I got mine at Home Depot. Be sure to get a tubing cutter that can handle 1 1/8" OD tubing.
Glue gun (high heat) and glue sticks (0.28" diameter, multi-heat). Any crafts store. I got mine at Walmart.
Other materials/equipment -- anywhere

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