ICE Devices

Mass Spec Demonstration Board

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45 min

Mass Spec Demonstration Board

By Robert Shaner

The demonstration board that you are about to assemble is designed to be used on an overhead projector to help students visualize what takes place in an actual mass spectrometer. Using the board, you can easily convey to students how electric and magnetic fields deflect various ions. Ball bearings of different sizes represent the ions being released from an ion gun, which is modeled by a chute. Adjusting the slope of the board (and thus the chute) is analogous to varying the electric field strength. Changing the position of a magnet varies the magnetic field strength on the ball bearings as they roll through the "analyzer."

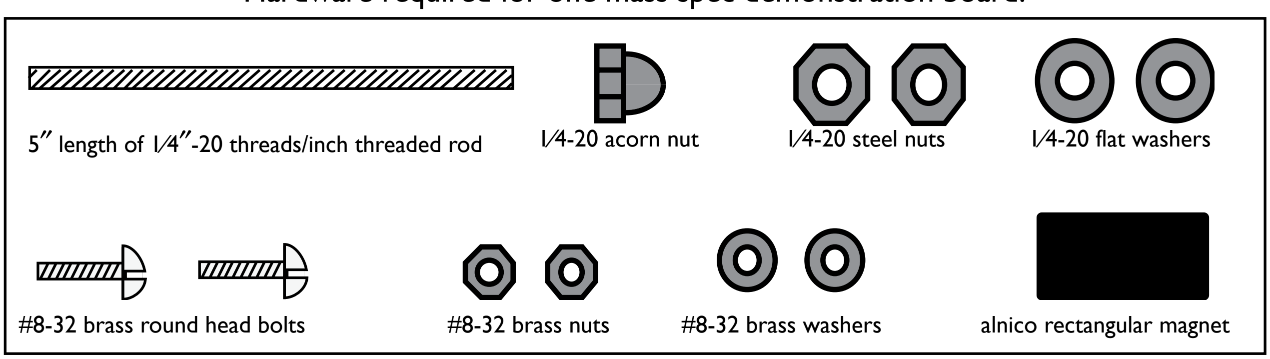
Materials

The 1″ = 1″ templates on pages 33 and 34 of this document are useful references.

- __ *9″ × 12″ × 1/4″ sheet of acrylic plastic (Lucite® or Plexiglas®) with square corners, available from a hardware store or a plastics supply house (see step 1)*
- __ *table saw (optional, see step 1)*
- __ *file and sandpaper (see step 1)*
- __ *1″ wide, or wider, masking tape, about 14″*
- __ *8″ × 3″ piece bubble plastic as used for packing fragile items (small bubbles)*
- __ *1 alnico large rectangular magnet (available from a hardware store)*
- __ *2 ea. 1/4″-20 flat washers*
- __ *2 ea. 1/4″-20 steel nuts*
- __ *1 ea. 1/4″-20 acorn nut*
- __ *1 ea. 5″-long 1/4″-20 threaded rod*
- __ *2 ea. #8-32 brass washers*
- __ *2 ea. #8-32 brass nuts*
- __ *2 ea. #8-32 1″ brass round head bolt*
- __ *3 ea. or more ball bearings of varying sizes (available from a hardware store)*
- __ *1 ea. glass or plastic marble*

Hardware illustrated below (items from the alnico magnet through the #8-32 brass round head bolts)

Hardware required for one mass spec demonstration board.



__ *drill*

__ *1/4″ and 1 1/64″ drill bits*

__ *(optional) 1/8″ drill bit; 1/8″-dia. nail or pin*

__ *20 mL acrylic solvent such as acetone (nail polish remover) or commercial product such as "Plaskolite® Solvent Cement" (available from hardware stores or home improvement centers)*

__ *10-mL syringe or eye dropper*

Assembly Directions

1. It is best to let your plastics supplier cut the plastic sheet to the correct dimensions, listed below. If you need to do the cutting yourself, follow the suggestions here and use the layout on page 34.

   If you use a table saw with a fine-toothed blade such as a veneer cutting blade or with a carbide blade designed for plastic, you will get fairly smooth edges. When laying out the cutting pattern, allow at least 1/4″ for each cut for the width of the blade. Cut the plastic into the following dimensions:

   __ *1 piece at 9″ × 8″ × 1/4″*

   __ *1 piece at 9″ × 1″ × 1/4″*

   __ *2 pieces at 4-1/2″ × 1″ × 1/4″*

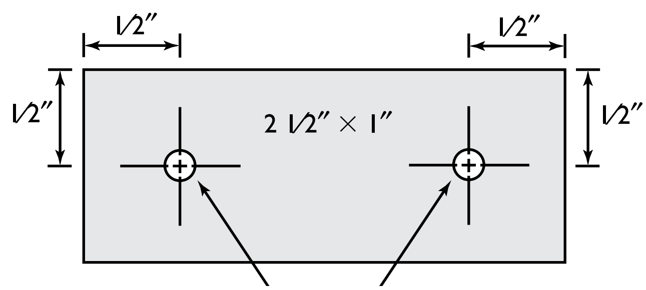
   __ *2 pieces at 2-1/2″ × 1″ × 1/4″*

   __ *2 pieces at 1/2″ × 1″ × 1/4″*

2. A full-scale template for drilling the 2 1/2″ × 1″ × 1/4″ plastic piece appears below. Copy and cut out the template. Align the edges of the template with the matching plastic pieces. At the following positions drill two holes in this acrylic strip:

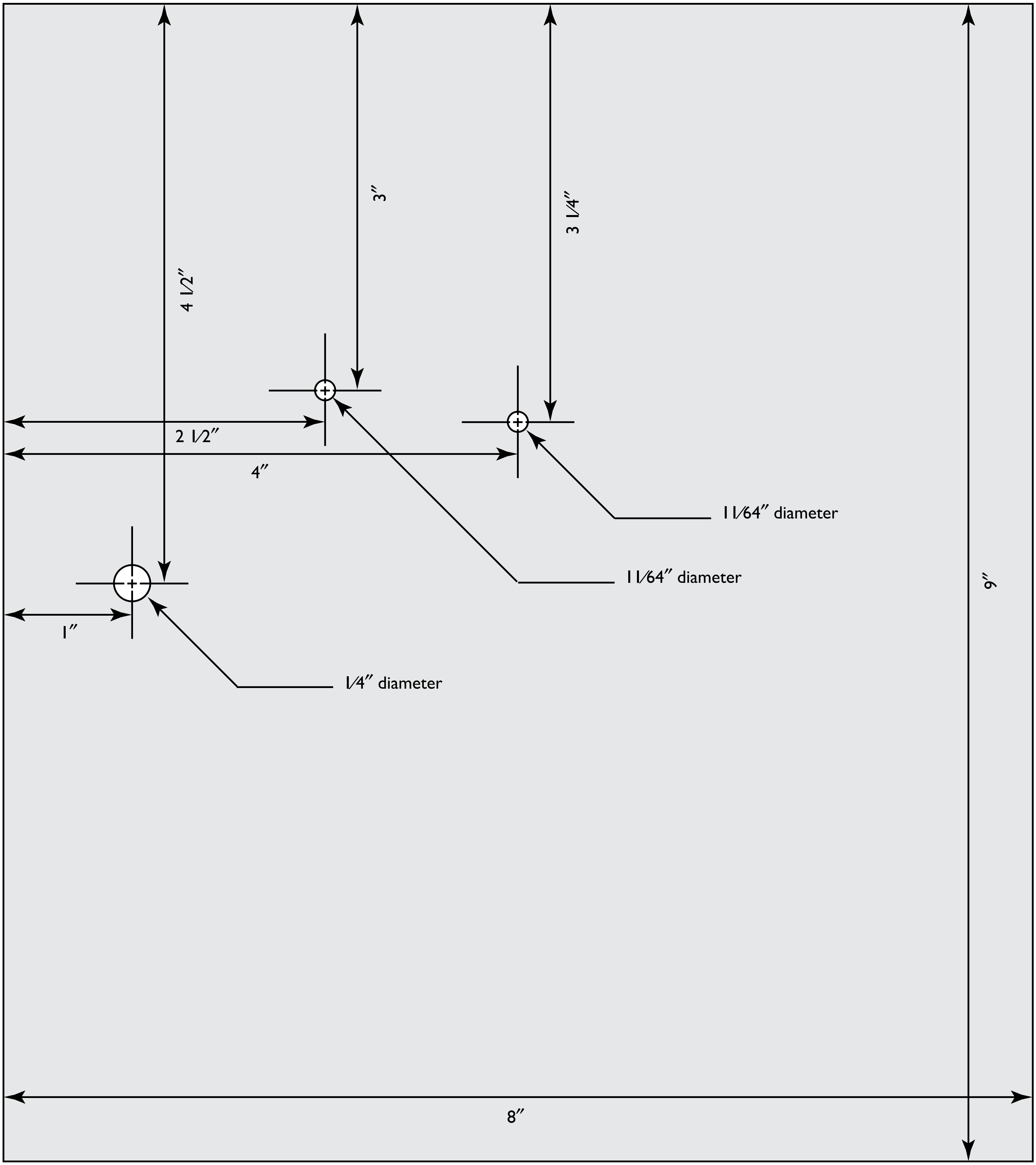
On the 2 1/2″ × 1″ × 1/4″ strip (shown below)	***Drill Size***
1/2″ from the right side and 1/2″ from the top	*1 1/64″*
1/2″ from the left side and 1/2″ from the top	*1 1/64″*

Template for drilling the 2-1/2″ × 1″ × 1/4″ acrylic piece of the mass spec demonstration board. (Scale: 1 inch = 1 inch)



On the next page of this document is a template for drilling the 9″ × 8″ × 1/4″ plastic piece. Copy and cut out the template. Align the edges of the template with the matching plastic pieces. At the positions shown in the table below drill three holes in the 9″ × 8″ board.

On the 9″ × 8″ × 1/4″ board	***Drill Size***
4 1/2″ from the right side and 1″ from the top	*1/4″*
3″ from the right side and 2 1/2″ from the top	*1 1/64″*
3 1/4″ from the right side and 4″ from the top	*1 1/64″*



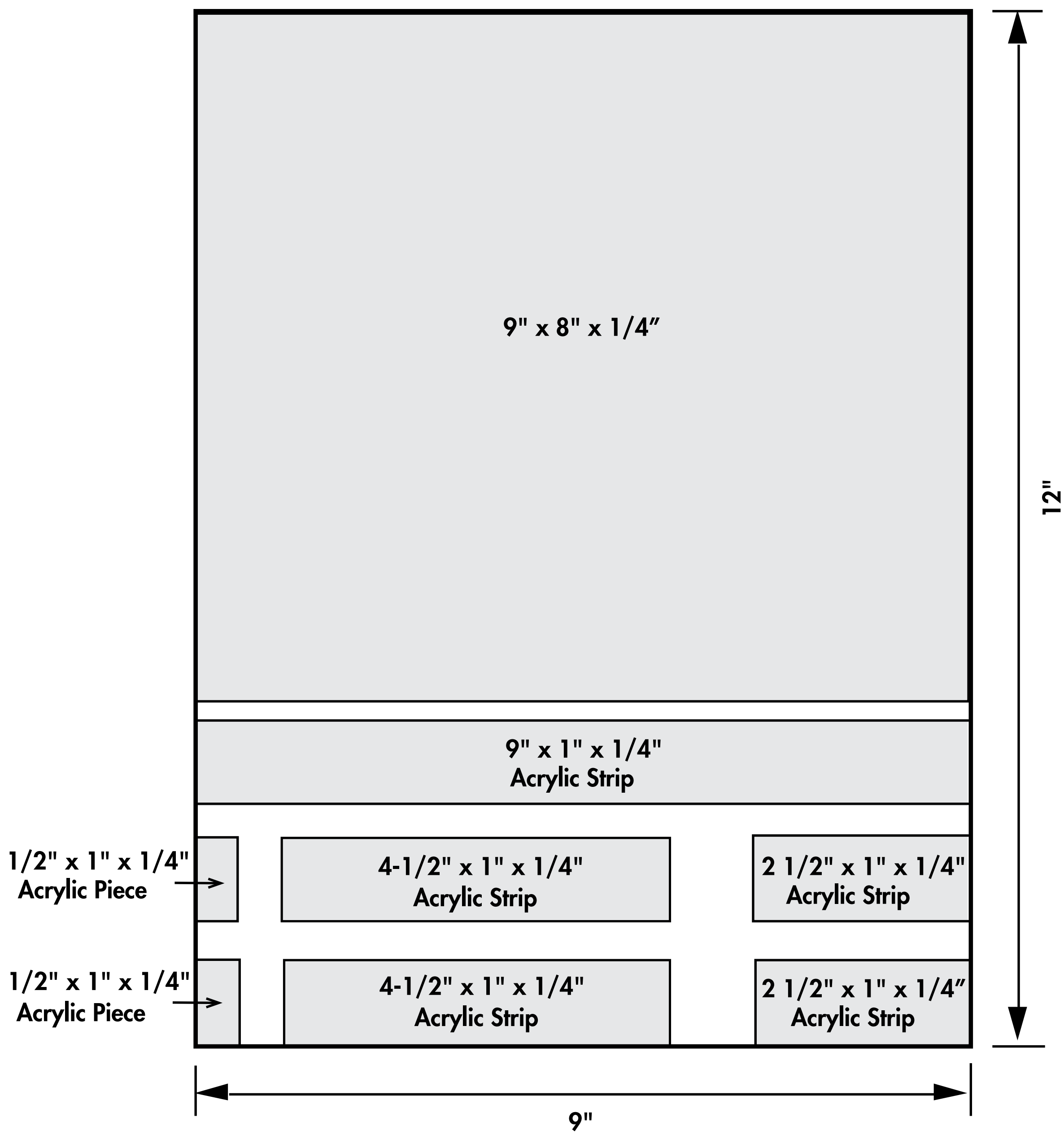
Template for drilling the 9″ × 8″ acrylic piece of the mass spec demonstration board. (Scale: 1 inch = 1 inch)

3. Place all the plastic in front of you. Position the 9″ × 8″ board so that the drilled holes are at the top and to the right of the board. Remove any contact paper from the top surface. Keep the contact paper on the bottom surface to protect it from scratches. Remove the contact paper from each acrylic strip.

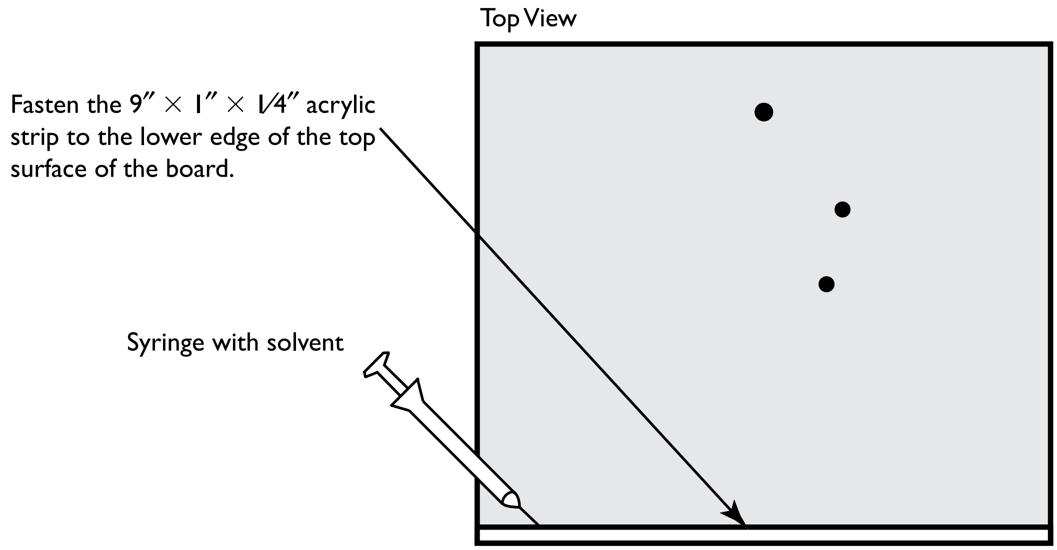
4. Fill the 10-mL syringe with acrylic solvent. ⚠ *Use adequate ventilation when working with the solvent. Avoid breathing the vapors.*

   In the next few steps you will make a shallow three-sided box out of the board and 5 acrylic strips. The inside walls of the box will be 1″ high.

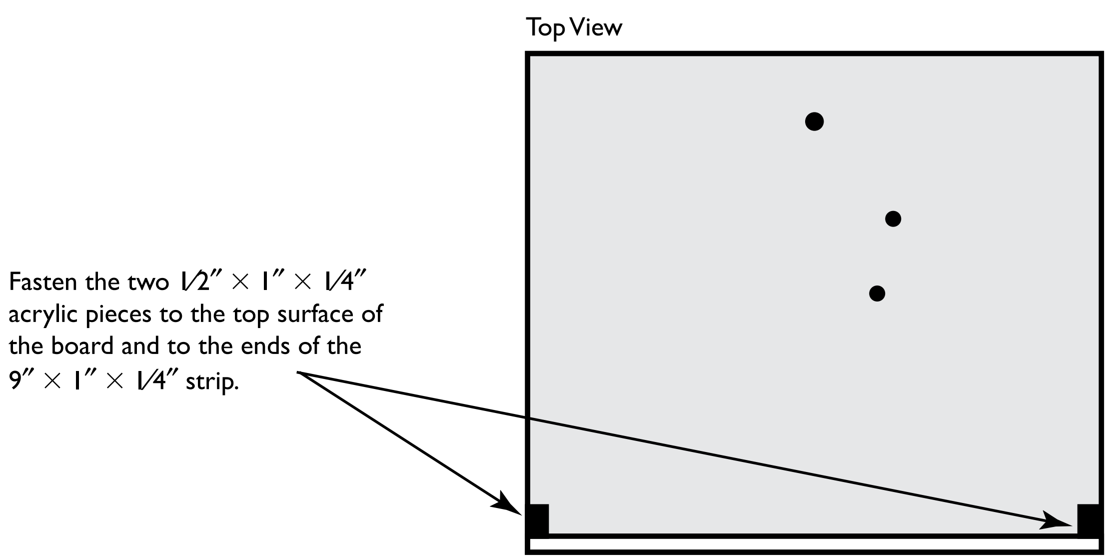
Layout for cutting pieces for one demonstration board (Scale: 1 inch = 2 inches)



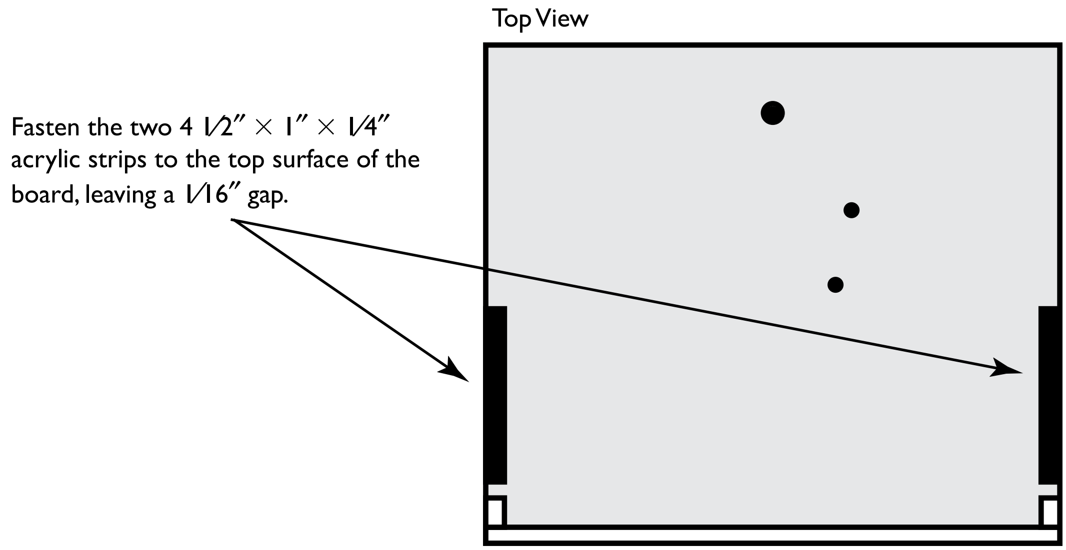
5. Place the narrow surface of the 9″ × 1″ × 1/4″ acrylic strip on the top surface of the board, along the lower 9″-edge. Gently hold the acrylic strip to the board and slowly and sparingly apply the solvent by running the tip of the syringe along the adjoining edges. The solvent should easily flow between the two pieces as you move along the edge. If the solvent does not flow between the pieces, you may be applying too much pressure. You only need to hold the pieces together for about 10 seconds. During that time you may still move the strip if you need to make slight adjustments. Let the pieces set for 30 seconds before going on to the next step.



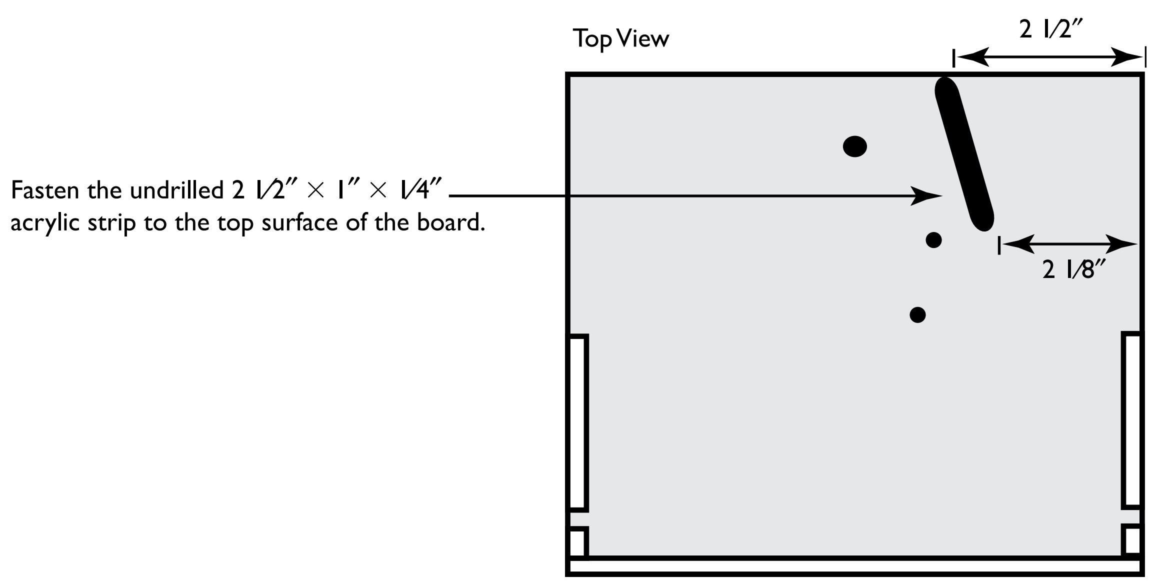
6. Position the 1/2″ × 1/4″ surfaces of the smallest acrylic pieces along the bottom sides of the top surface of the board. Your box should now have corners as in the figure below. Fasten the strips into place using the same technique as above.



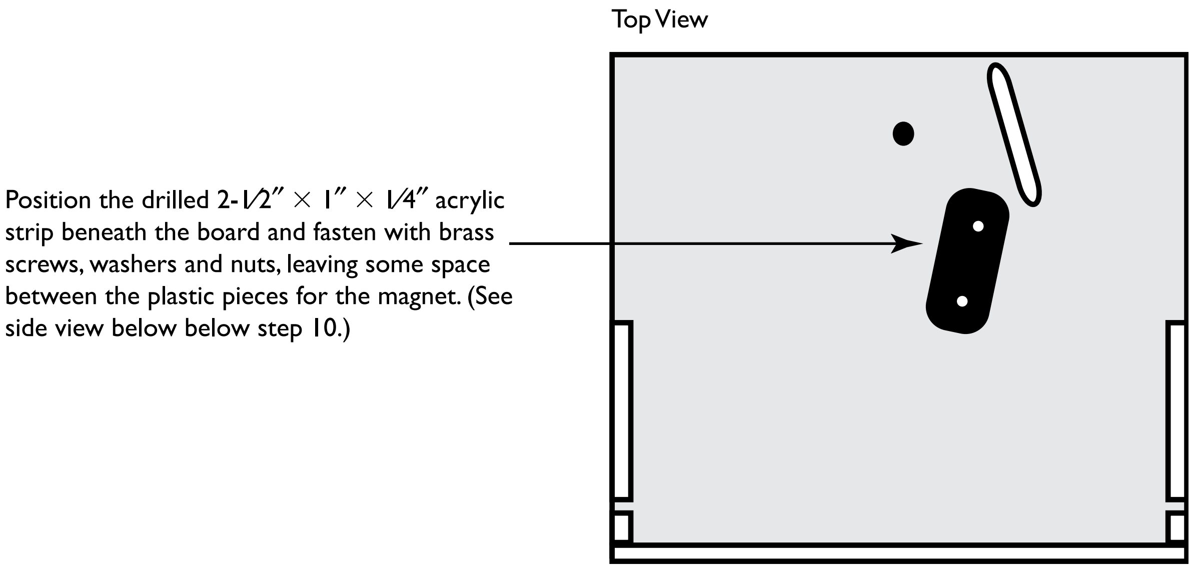
7. Position the two 4-1/2″ × 1″ × 1/4″ acrylic strips on the top surface of the board, along the sides. Leave about a 1/16″ gap to the 1/2″ pieces that you attached in step 6 (see figure below). Fasten the strips into place using the same technique as above.



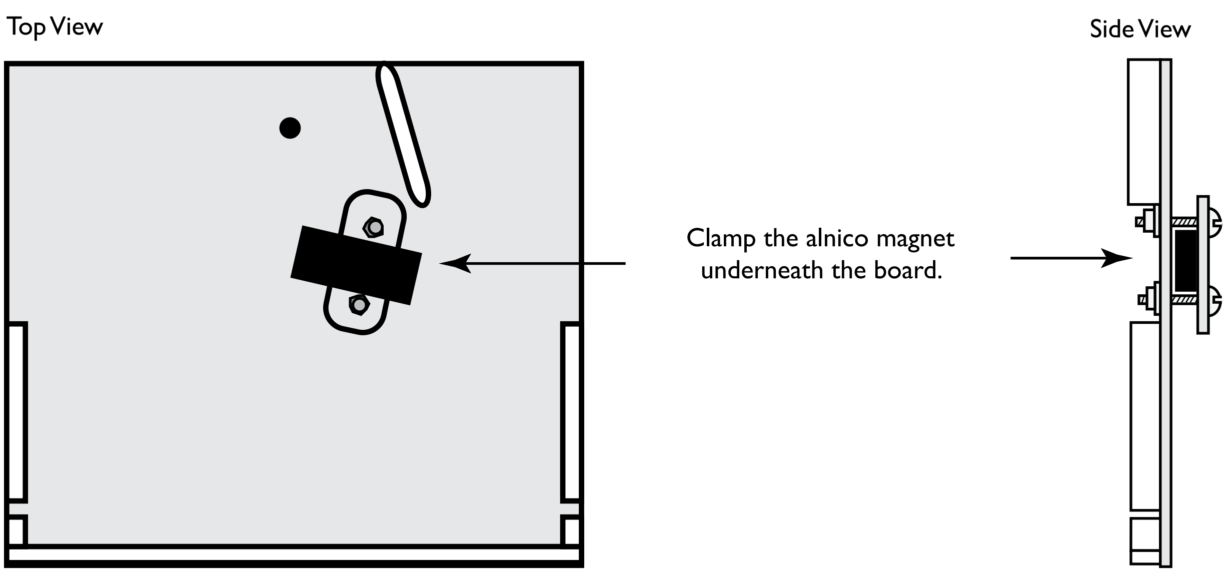
8. Place the undrilled 2 1/2″ × 1/4″ × 1″ strip with its long narrow side on the top surface of the upper portion of the board. The upper edge of the strip should be 2 1/2″ to the left of the upper right corner of the board. The lower edge of the strip should be 2 1/8″ to the left of the right side of board. Fasten the strip to the board. This strip will serve as the chute for the ball bearings.



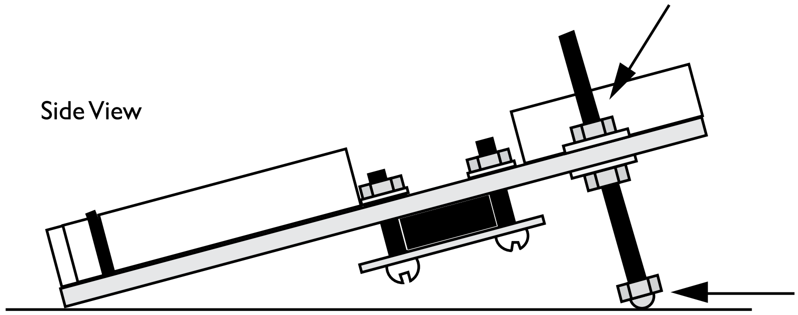
9. Remove the contact paper from the underside of the 9″ × 8″ board. Locate the 2 1/2″ × 1″ acrylic strip with the two drilled holes. Insert a 1″-long #8-32 brass bolt into each hole of the strip. Position the strip on the underside of the board, aligning the holes with the two 11/64″ holes on the board. Push the bolts up through the board and place a brass washer onto each bolt. Place the brass nuts over the washers and twist them down only a couple of turns, leaving space for the magnet between the two plastic pieces.



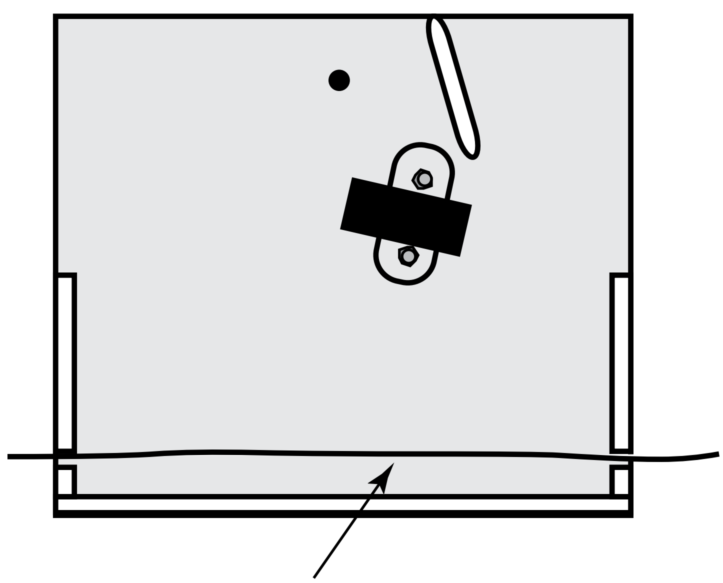
10. Place the alnico magnet between the board and the strip underneath the board. Tighten the nuts to hold the magnet firmly, but allow some motion to adjust its position slightly.



11. Position a washer onto the 5″ threaded 1/4″ rod. Screw a 1/4″ steel nut onto the rod and push the rod down into the board. Position a second washer and nut on the rod underneath the 9″ × 8″ board. These nuts and washers will be used to adjust the slope of the board. Once you determine the approximate slope that you want, simply tighten the nuts to that position. Typically the slopes are set to about 20° from the horizontal. To protect a table top or the glass of an overhead projector from being scratched by the threaded rod, tighten an acorn nut on the bottom of the rod.



12. Insert the strip of masking tape through the 1/16″ notches across the bottom of the demo board with the sticky side pointing towards the top of the board. Leave the tape loose, not taut. Roll the bubble plastic into a 8″-long cylinder and place this roll behind the tape to act as a cushion. This tape-and-bubble plastic assembly prevents the ball bearings from bouncing after they've been rolled down the chute. You may tell your class that this assembly simulates the "detector plate" of the mass spectrometer.



Insert a 14″ strip of masking tape through the notches, leaving it somewhat loose. Then insert the roll of bubble plastic.

13. Both the slope of the board and the position of the magnet determine the trajectories of the ball bearings down the demo board. Each ball bearing should have its own trajectory, preferably landing as far away from the other bearings as possible. It is easiest to fine tune the trajectories by sliding and rotating the magnet, millimeter by millimeter, about its original position until optimal conditions are reached.

Mass Spectrometry

Mass spectrometry is an instrumental method used to identify molecular compounds.

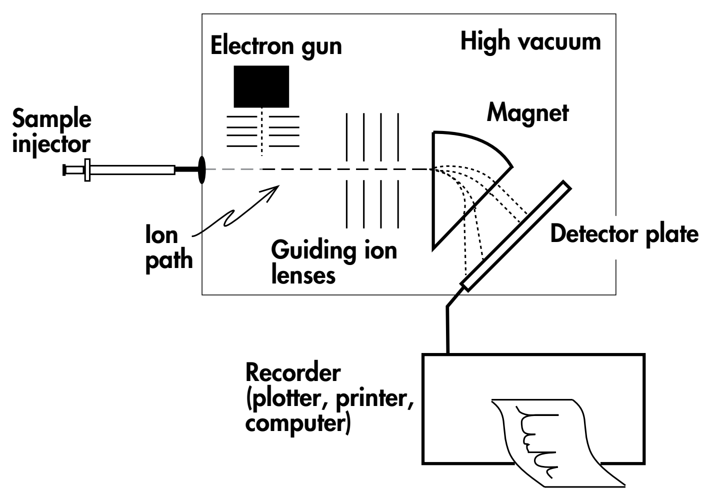
The origins of the mass spectrometer date back to the turn of the century. In 1898, Wilhelm Wien discovered that beams of charged particles could be deflected by a magnetic field. A few years later, from 1907 to 1913, J. J. Thomson, the English physicist who also discovered the electron, experimented with positively charged particles. In his work, these charged particles, called ions, when passed through a combined electrostatic and magnetic field, were deflected onto a photographic plate. Thomson found that the angle of deflection was dependent on the particles' mass-to-charge ratio. Thomson replaced the photographic plate with a Faraday cup located behind a narrow slit cut in a sheet of metal. By varying the magnetic field, he was able to change the deflection angles of particles so that only those particles with a particular mass-to-charge ratio passed through the slit. Other particles hit the surrounding metal plate. Those particles passing through the slit hit the grounded metal cup. This induced a current in the cup that was measured by an ammeter. Because the particles were charged, it was easy to measure how many there were. Thus Thomson could be credited with the construction of the first mass spectrometer. Later, other scientists developed more sophisticated focusing techniques and improved the resolving power of the instrument.

The sketch below shows the main parts of a modern mass spectrometer. The sample is usually a liquid, which can be injected into the mass spectrometer through a syringe. Inside the mass spectrometer there is high vacuum, so the sample vaporizes. It then passes through an "ionization chamber" in which high currents of electrons bombard it, breaking it apart and removing electrons to leave behind positive cation fragments. These ionic fragments are guided by electrostatic lenses into an analyzer magnet where magnetic and electric fields cause the different fragments to travel along different paths, as the demonstration board shows. The mathematical expression for the motion of the ions of charge e and mass m through the electromagnetic field B of a mass spec is

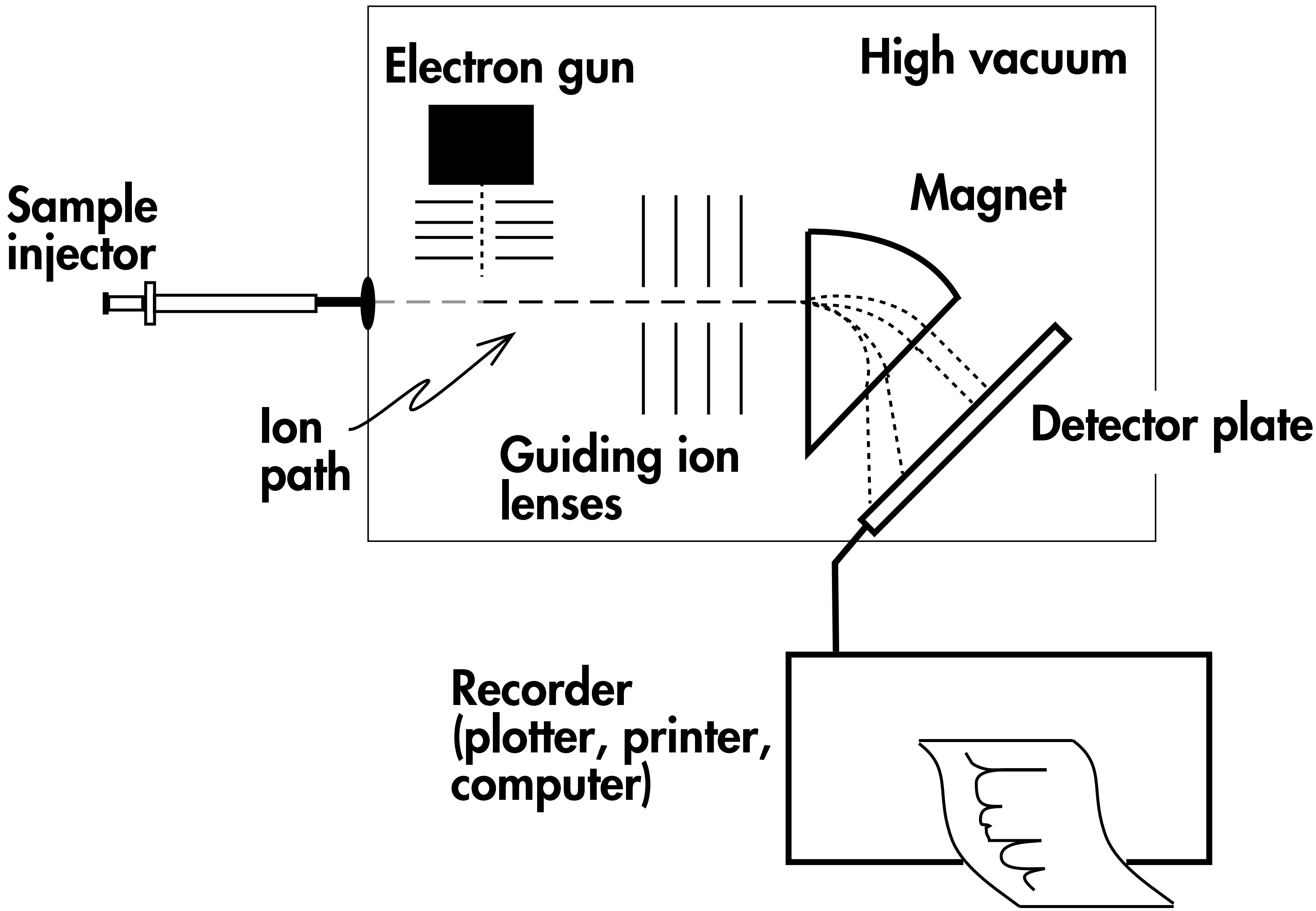
$$1/r^2 = [B^2/2V] \times e/m$$

Thus, r is the radius of a circular path taken by the sample ions accelerated through the magnet by a voltage difference V. This radius is determined by the geometrical design of the instrument.

Usually in modern mass spectrometers, only particles traveling about a certain radius r are detected (that is, r is constant in the equation above). The magnetic field strength B is also held fixed. The user scans the voltage V and a map of the number of e/m ions detected at each voltage is plotted, or stored in a data file in a computer for later analysis.



Schematic showing main components of a mass spectrometer.



Main components of a magnetic mass spectrometer.