Build and Test a Single Wire Gas Proportional Chamber

Proportional chambers are devices that measure the position of, and the energy deposited by, a charged particle as it travels through a gaseous volume. A charged particle loses energy to the medium through which it travels by a variety of mechanisms; for example, by elastic collisions with atoms, by exciting the atoms of the medium, by emitting Cherenkov radiation or by outright ionization of atoms. Proportional chambers are dependent on the last case mentioned, i.e. the creation of electron-ion pairs. In the device you are building, a very thin central sense wire (20 micron diameter gold coated tungsten wire) is at a high positive potential (hence positively charged and therefore attracting the electrons) and the cylindrical shell (1.22 cm inside diameter copper pipe) around the wire is at a low potential (thereby attracting the positive ions). The electrons experience an electric field and therefore drift toward the wire. At a distance within a few wire radii from the center, the electrical field gets very strong, the electron kinetic energy becomes large enough that when electrons collide with gas molecules they free additional electrons, which in turn accelerate and collide to create more electron-ion pairs (this process is called avalanche multiplication). It can be arranged so that a signal, equivalent to the order of 10^6 electrons, is produced on the wire. This produces a measurable signal after amplification. Due to their low mass, the electrons move much faster than the ions, so that they are collected rapidly. The bulk of the electronic signal that is observed though, is produced by the positive ions moving away from the central wire (you are directly observing the energy given by the field used to move those positive ions away from the central wire). The chamber is filled mostly with Argon, a noble gas. A small (10%) additive in the form of methane is present in the gas for the purpose of quenching the multiplication so that the system does not run away.

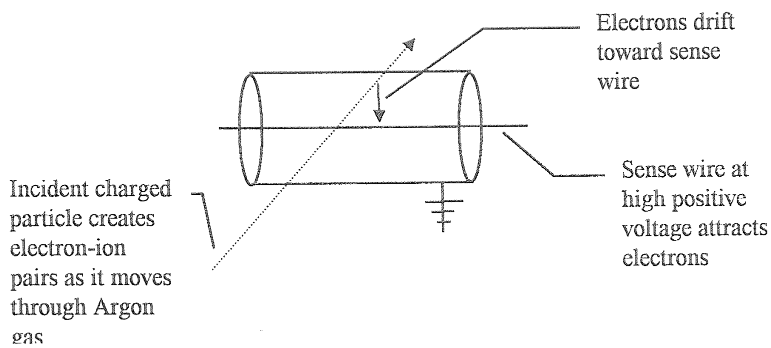

Figure 1.

Assembly of the Chamber

Refer to the diagram provided below to identify parts. The chamber is symmetric about the middle, thus only one half of the chamber is shown. Examine the finished chamber on display and compare to the diagram shown in Figure 2 before proceeding with assembly.

1. Clean all the parts with alcohol. Particularly important is the inside of the copper tube. Grease or dirt left inside the chamber can cause electrical breakdowns and the out gassing from the dirt can poison the gas that will fill the chamber.

2. Put a drop of super glue on the plastic bushing, swirl the drop all the way around the bushing. Then quickly insert the plastic bushing into the brass end cap. Do insertion with a quick sure motion, otherwise the glue will set in the midst of insertion. (Be careful with super glue, it has cyanide in it!)

3. Wrap one turn of teflon tape around threads on each side of copper tube. Attach brass tees to both ends, tighten slightly with a wench.

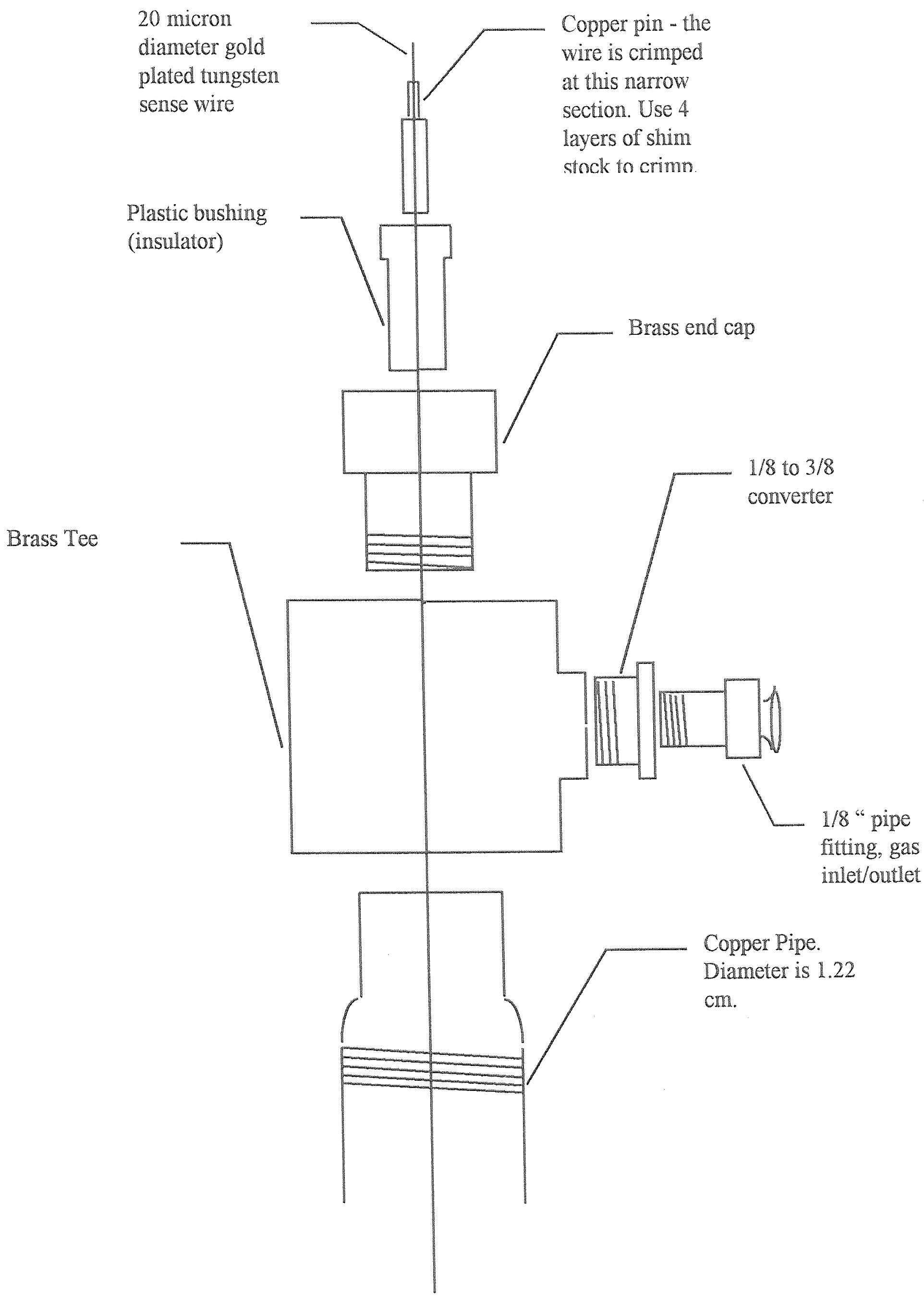

Figure 2. Exploded View of One End of a Single Wire Proportional Chamber. All three threads that fit into the brass Tee should have a single turn of teflon tape on them. The plastic bushing is held to the brass end cap by super glue. Similarly, the copper pin is held to the plastic bushing by super glue. The wire is crimped at the narrow end of the copper pin. Note: the two ends are identical.

4. Lay out all the parts as shown in Figure 2. Stringing starts at one end and proceeds all the way through to the other. Gently feed (the wire breaks easily) the wire from the spool by turning the spool while maintaining minimal tension on the wire. Thread wire through the cooper pin; while threading it helps to gently rotate the piece you are threading into - this stops the sharp tip of the wire from getting stuck on the wall of the pin. If the wire has or develops sharp kinks, cut them off with the scissors. Kinks are difficult to thread, and will adversely affect chamber operation Then thread through plastic bushing, brass end cap. When you get to the copper pipe, it is useful to loop the wire around a small screw and secure it by a nut. In this way you can lower the wire down the copper tube. On the other side of the tube you continue threading, but now in reverse order: through brass end cap, plastic bushing and finally through the copper pin.

5. Start at one end of the detector. The wire should have been threaded through all elements of the detector. Put a drop of super glue on the thicker part of the copper pin, swirl it around, and with one smooth powerful motion push the pin into the plastic bushing (do this fast, else the glue will set up before you can shove the pin into its place. Examine completed detector to see how far the pin goes in.).

6. Crimp the wire at the short thin end of the copper pin. You must put four layers of the thin brass shim stock around the pin, else the crimp will not hold the wire in place (the crimper jaws are slightly too wide)

7. Wrap one turn of teflon tape around the threads of the end cap, then gently (be careful that wire remains free) screw the end cap into the tee. Attach the brass end cap on the other end of the detector in the same way. Glue the other copper pin into place.

8. At this point we want to put tension on the uncrimped end of the wire and then crimp it in place. Have your lab partner firmly hold the chamber in a vertical position (loose wire hangs down) by pressing it against a table edge. Attach the 50 gram weight to the free end of the wire (do this very gently, lower the weight after attaching to wire very slowly, else the acceleration of the weight will break the wire). The weight has a little screw at the top - wrap wire around screw and then tighten screw to secure wire to weight. Using four layers of brass shim stock, crimp the wire.

9. Put one turn of teflon tape on each of the 1/8 to 3/8 converters and screw them into place, tighten with wrench. Attach gas inlets, tighten with wrench.

Electrical Testing of Detector

The wire must be continuous from one end of the chamber to the other, and it must be insulated from the chamber body. Use an ohm meter to measure the wire resistance (from one end to the other); you should get about 20 - 30 Ω. Check that the wire is not short circuited to the chamber body. Check that good electrical contact exists between the various components making up the chamber body.

Gas Testing of Detector

Gas must be able to flow through the chamber. Attach a 1/8 inch plastic tube to one of the chamber inlets. Attach other end of plastic tube to the gas manifold on the workbench. Turn on large valve on gas cylinder, adjust flow- meter to over 1 ft^3/hr. Feel if gas is coming out of outlet on other side of the chamber. Reduce gas flow to 0.2 ft^3/hr. Attach long plastic tube to outlet, allowing other end to dangle out the window. In this way gas will flush all the air out of your chamber, leaving a clean and pure argon-methane mixture inside.

Attaching the Electronics

The sense wire will be at 1200 to 1300 Volts, thus you do not want to touch the copper pins when the high voltage is turned on - depending on the circumstances, you could receive a nasty shock. So make sure the high voltage supply you intend to use is shut off. Cut off a piece of high voltage insulator about an inch in length and insert it over one of the copper pins (this pin will not be used for anything and we want to shield you from touching it). You will connect the instruments as shown in Figure 3. Now you are ready to attach and test the electronics.

1. Attach the jack at the end of the cable coming from the preamp input to the exposed copper pin. Do this by simply pushing the jack over the pin; for a good contact, the jack should go over the thick part of the pin. Pull the black plastic insulator over the jack. Cut a piece of aluminum foil and making sure that the foil does not come in touch with the jack or the wire leading to the jack, form a hood (cover, jacket, whatever) extending from the brass tee all the way to the copper sleeve on the cable. Take two pieces of single strand wire and tighten around foil at tee and at copper sleeve. This foil serves two purposes: it provides a ground to the detector body and it shields the cable that takes signals to the preamp from external noise. External noise sources range from radio signals all the way to electrical noise made by motors in the building.
2. Attach a BNC cable from the preamp output (labeled "dE/dX" or "ENERGY") to the oscilloscope. Look at signals on the scope. If all is well, you should see 20 to 50 mV noise levels and nothing else. If you see significantly more noise than that, attach an aluminum foil hood over the other (unconnected but insulated) pin. If you still see excess noise check the aluminum foil hood for contact with the chamber body and with the ground of the cable.
3. Calculate how long it takes for the gas to completely flush the chamber about five times. Wait at least this long.
4. Put a radioactive source next to center of copper tube. Connect the high voltage BNC cable from the power supply to the "bias" input of preamp. Turn on the high voltage power supply and set the voltage to +1000V. Look at scope. Slowly increase the voltage until you begin to see distinct pulses on the scope. Signals normally start appearing at about +1200 V, but this depends on gas purity, precise wire diameter, etc.
5. Make sure what you see has to do with the radioactive source: if you remove the radioactive source, signals should disappear. Conversely, by placing the source next to the chamber, the signal pulses should reappear.

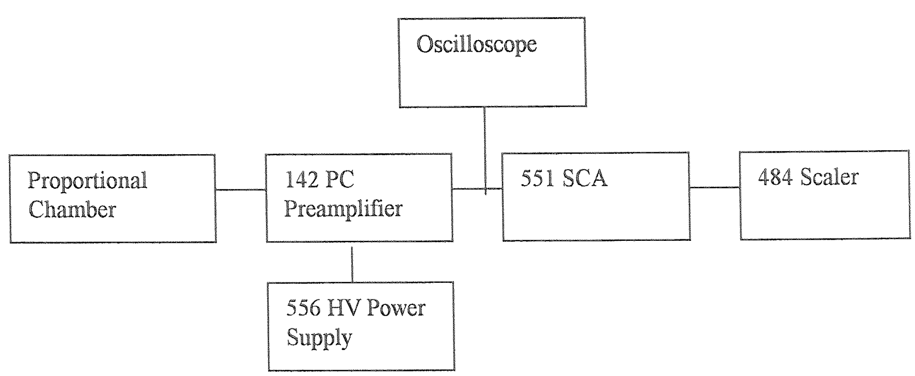

Figure 3. Electronics connections

Data Taking

1. Note the voltage and draw a figure of the pulse shape that you observe on the oscilloscope. Use scope settings such that you can measure the width (in time) of the pulses.
2. Request three radioactive sources from your instructor. Attach the preamp output to a counter. For each source, compare the count rate with and without a radioactive source. Take data runs long enough such that you can convince an unbiased observer that your detector really works. Note: The SCA sets a digital output pulse for the counter. Its operation is very similar to setting the triggering level on the scope: at a particular voltage level, an operation happens. On the scope, the operation is the displaying of the waveform that you were triggering for. With the SCA, the operation is to output a digital pulse. On some of the scopes we have, you can measure counts AND look at waveforms. This can save you some time if one of these scopes is available.

Questions and Exercises

1. Consider your chamber operating at a voltage of 1300 V. Assume the chamber is infinitely long, and use the symmetry inherent in the cylindrical geometry. Calculate the expressions for the electrical field and electrical potential as a function of distance from the center of the chamber. Units should be Volts/m and Volts, respectively. Plot these quantities as a function of r, the radial distance from the center of the chamber.
2. Calculate the capacitance per unit length for your detector.
3. Let α (called the first Townsend coefficient) be the number of electron-ion pairs produced per unit path length, therefore $1/\alpha$ is the mean free path for ionization. Consider an electron liberated in a region of uniform electric field; after drifting a distance of $1/\alpha$, one additional electron will be produced, and two electrons will continue to drift; each of these, after drifting an additional mean free path will produce another ion pair, giving four electrons total… and so on. Show that if N_0 electrons start from a given position, the number of electrons present at a distance x from where they started is given by the expression $N(x)= N_0 e^{\alpha x}$. The multiplication factor M is defined as $N(x)/N_0 = e^{\alpha x}$. In the case of a non-uniform electric field, $\alpha= \alpha(x)$ and the multiplication factor is modified to be $M=\exp[\int\alpha(x)\,dx]$, the limits of the integral are, of course, over the drift distance of interest.
4. For α not too large, the approximation $\alpha=kN\varepsilon$ holds, where ε is the electron energy (in eV), N is the number of gas atoms per unit volume and k is a constant with value $k=1.81 \times 10^{-17}$ cm^2/V for Argon. On the average, the electron energy will be equal to the change of potential energy as it moves one mean free path, the distance between subsequent collisions. Use this information to first derive an expression for $\alpha(x)$, then evaluate the multiplication factor assuming that multiplication starts at a distance of 5 wire radii from the center of the chamber.