Proportional Counters and Tubes

Proportional tubes, proportional wire chambers, and drift chambers are in very wide use in high energy physics experiments for particle position measurement and for energy measurement. In these detectors one or more very fine wires are stretched within a gas volume. The wires are at positive potential with respect to the outer conductor so that electrons are attracted. The main component of the filling gas is usually argon but polyatomic additives are essential.

If the particle to be detected is a charged particle (we will be using electrons) it ionizes the filling gas on its way through the detector. The electrons that are released drift toward the positive wire. When they approach within a few diameters of the wire the electric fields become very large and secondary ionization takes place. An avalanche develops and a very large number of ion pairs are created very close to the wire. The electrons produced in the avalanche are very quickly collected at the wire while the positive ions move slowly in the opposite direction through a large potential gradient. This motion of positive ions induces a negative pulse on the wire that can be detected as a current flowing through a resistor connected to the wire. If the incident particle is a low energy x-ray (we will use a ^{55}Fe source which emits a 5.9 keV x-ray) then the initial interaction is photoelectric effect in argon; in most cases the entire x-ray energy is converted to ionization that is collected.

The avalanche process near the wire provides an "amplification" of the initial charge deposited by the primary particle. This is sometimes called the "gas gain"; it is sufficiently large so that the output pulse can be observed on a scope. For use in logic circuits or pulse height analysis it is usually amplified further with a high gain current or charge amplifier.

See the references at the end of these instructions for more information of proportional tube detectors and related apparatus.

The proportional tube

The simplest device we will work with is a tube with a single wire. Replicated by the hundreds or thousands these are very popular in modern large detector systems. They are easy to make and parameters such as wire position are not very critical. The position resolution is, of course, comparable to the size of the tube but the energy resolution can be quite good. The time resolution is much poorer than with scintillators because the charge must drift to the wire and the time it takes to collect the charge (and see a signal) will depend where the energy is deposited by the ionizing radiation: near the wire or near a wall.

Construct a proportional tube detector

Rectangular cross section conductive plastic tubes are provided along with plastic end caps and small copper tubes for gas flow and to fix (hold) the central wire (0.0025 inch diameter). Ground wires are connected to each end of the plastic tube and are heated with a soldering iron; they melt into the plastic slightly and make good electrical contact. After the wire is strung the end caps are glued in place with "5 minute epoxy". An appropriate tension of about 150 grams is applied to the wire which is then soldered to the small copper tubes at each end. The detailed construction steps follow below.

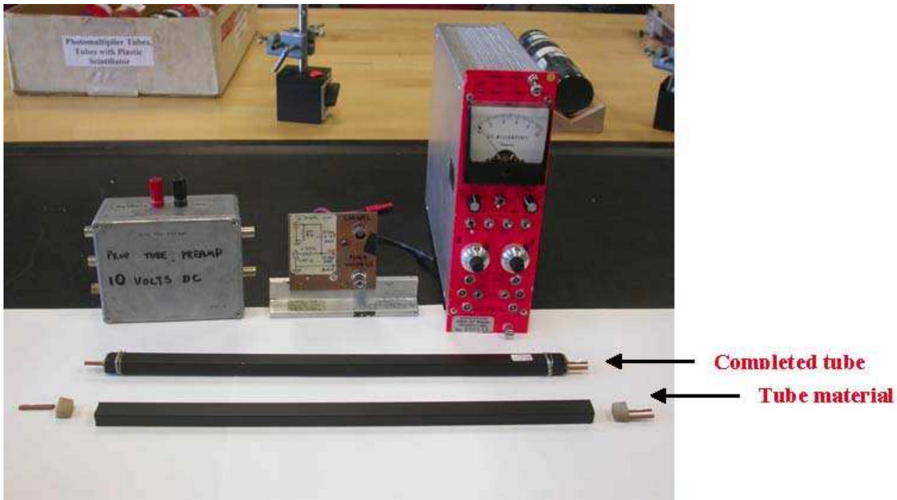

Figure 1: Materials and equipment used in the proportional tube detector experiment. In the foreground are the parts used to build the detector, and an assembled version. In the background are, from left to right, the charge-sensitive preamp, the capacitor decoupling card, and the NIM current-limiting HV supply.

Please pay ***careful attention*** to the order of the steps below. If you solder both ends of the tube before you have finished with the gluing, you may get a defective tube because the wire may break or sag internally.

1. Plug in soldering iron and put some water on the sponge in the plastic box. The soldering iron tip can be cleaned when hot by wiping it on the sponge.
2. Lay out the pieces needed to construct the proportional tube:
   - 1 length of black plastic tubing.
   - 2 end plugs.
   - 2 large copper pieces (the gas enters and exits the tube through these pieces).
   - 2 small copper pieces (these pieces hold the center wire).
   - Center wire, approximately 4 foot length. This is the gold plated tungsten wire, 0.0025 in. diameter, on the large spool.
   - 2 eight-inch pieces of #20 solid copper wire (be careful: it is easy to confuse this wire with the solder).
3. Clean the black tube as follows: make a large swab by threading a piece of tissue through the loop in the end of the aluminum rod. Moisten the tissue with ethyl alcohol and swab out the inside of the tube. After the tube has dried, blow out any dust inside the tube with the can of compressed air.
4. Use the compressed air to blow any dust out of the holes in the end plugs and out of the copper fittings.
5. Clean the portion of the center wire that will be inside the black tube with ethyl alcohol and tissue. For proper tube operation it is important that the wire be free of any contaminants,

e.g., skin oil, dirt, dust, etc. After cleaning the wire, take care not to touch or contaminate the portion that will be inside the tube after it is assembled. String the center wire through the black tube, through a plug at each end and then through a small copper piece at each end. The copper pieces should be oriented so that the openings both face the same wider side of the tube body. The center wire should be handled very carefully as it kinks (and breaks!) easily, and a kink in the section within the tube will prevent the tube from operating properly.

6. Push the end plugs snugly into the black tube and then seat all the copper pieces in the plugs.

7. Leave 12 to 15 inches of center wire extending from each copper piece. Solder the center wire to one (**only one at this time**) of the copper pieces at the opening in the side of the piece. Make sure that the solder plugs up the opening toward the tube to prevent leakage of gas from the tube. (The tube is operated at a slight positive pressure).

8. Some comments on epoxy: "5 minute" epoxy means that after mixing the epoxy, you can work with it for about 5 minutes. For the epoxy to cure, 30 minutes or more is required. Please try to keep the epoxy from dripping onto permanent surfaces. Keeping excess epoxy on (disposable) paper surfaces will help make for a neater work area.

   Put a small amount of 5 minute epoxy on a sheet of paper and mix it thoroughly (about 2 minutes) with the handle (wooden end) of a cotton swab. At both ends, apply the epoxy to the joint between the plug and black tube, and to where the copper pieces enter the end plug. These joints must all be gas tight for the tube to work properly. Allow the epoxy to dry for at lest 15 minutes, taking care not to find the tube stuck to some inconveniently massive object (table) after the epoxy has dried. (Hint: lay it cross-wise on the foil-covered block.)

9. Take the lengths of #20 wires and at each end wrap two turns around the black tube. Twist the ends of the wire together to tighten it lightly around the tube. Solder the twisted portions of each wire so that the wire slightly melts into the black tube and then trim off the excess wire. Soldering is necessary to get sufficiently good electrical contact between the wire and the tube. The resistance between the wires should be roughly 1 to 2 megohms (the plastic tubing conducts weakly, but well enough to serve as the ground side of the tube). These wires provide the ground connection when the tube is in operation.

10. Use the copper alligator clip (with a short, curved piece of bare wire attached) to grab the small copper fitting to which the center wire is soldered. Hook the wire attached to the alligator clip over the screw in the plywood board.

11. Using the eye-bolt weight in combination with a small C clamp, pinch the center wire about 10 inches from the copper fitting and carefully hang the clamp+weight over the rounded edge of the board.

12. With the wire under tension, solder it to the remaining copper piece, again being careful to fill the hole with solder to make it gas tight. Maintaining tension during this operation is critical.

13. After soldering the wire, remove the C clamp/eye-bolt weight, and trim off the excess center wire with a pair of scissors.

14. Once the center wire is soldered at both ends it is important to avoid flexing the tube as this can easily cause the wire to break.

15. Unplug the soldering iron.

After you have assembled the counter and the epoxy has hardened you need to check the continuity of the central wire and measure the resistance between the grounds on the outside (a few Mega ohms is typical). The proportional counter can then be connected to the gas system using the provided tubing. We use argon and about 10% CO_2. The gas is mixed using a mass flow controller. Instructions on the use of this mixing system will be provided in the lab. Be sure you understand the operation of the gas mixing system before opening any valves. Also remember to shut valves, especially the main gas cylinder valves before leaving. If the gas at the outlet of your counter does not bubble there is almost certainly a gas leak which needs to be found and sealed before you can proceed. The next step is to flush the tube with the operating gas to remove air. This can be accomplished by flowing through the tube the gas mixture of 90 units of argon and 10 units of carbon dioxide for 5–10 minutes. The tube is now ready and you should begin to look for pulses.

Energy measurements

For all measurements of the anode signal place the proportional tube on the aluminum foil side of the wood block. The aluminum conduction plane provides a good ground equipotential surface.

Caution: Use only the NIM positive current limiting power supply to power your proportional tube detector. The power supplies used with photomultiplier tubes should *never* be used with proportional tubes as they are not current limited and can supply a lethal amount of current.

Connect the high voltage supply specifically designed for proportional counters and drift cells to the "capacitor decoupling card", and connect the leads to the proportional tube: red to the center lead and black to one of the #20 wires on the plastic outer tube. The decoupling card circuit allows the small pulses to be sent to a sensitive amp while blocking the high voltage DC bias. The capacitor on this card can retain a charge for a very long time so use caution. The electrical shock you can get, while unpleasant, is not dangerous. Try a 1X scope probe to look at the output of this card. You will be looking at the signal across a 100k resistor. The observed signals will be weak and somewhat difficult to see. The signal will be small (about 20 mV) and will be superimposed on noise.

For your report. Explain the operation of the decoupling card.

Raise the voltage slowly while observing the current reading on the power supply. Why is the current large while you are changing the voltage? Go up to about 1.9 kV with the current meter set on the 10 μA scale; the current should not exceed 0.02 μA (use most sensitive scale) when it reaches a steady value.

At this point you could begin to look for signals from a source on the scope. Use the ^{55}Fe x-ray source to search for pulses. If they are still too small to see, the voltage can be raised further and eventually you should see them. If the power supply begins to trip and reset (you see the meter needle swing wildly), you need to lower the voltage and raise it again slowly. Once you get a stable operation, set the current meter on the second most sensitive scale. You may need to make several attempts to increase the voltage to an acceptable operating point before you get to a stable point with no trips! You may need to move the source away form the tube if you have difficulty finding a stable operation point.

The size of the pulses at a given voltage depends on the gas mixture and may depend on tube construction details. Note the pulse size and shape at a few high voltage settings. You probably will not be able to go above about 2.1 kV. (You don't need to sketch all versions, but make a table with pulse height versus voltage for a few settings.)

The gas gain can be well estimated by integrating the observed un-amplified signal and dividing by the mean number of electrons created by a ^{55}Fe x-ray. For a voltage that gives you good stable pulses, estimate the peak height and the decay time. Use these values (and their uncertainty) in the following exercise:

Exercise 1 *Calculate the total charge produced at the output of the proportional tube decoupling card. If it takes an average of 30 eV to produce an ion pair in argon, what is the "gas gain" of the proportional tube itself?*

Once you have established stable operation of the proportional tube you can connect the high gain charge amplifier to the signal output of the capacitor card. These amplifiers use a TRA1000 chip and should be run at a DC voltage of about 10 volts. If there is a problem with amplifier oscillation lower the voltage to about 6-7 volts and raise it again. Observe the output of the amplifier terminated in 50Ω. How much current gain have you achieved compared with looking at the pulse directly? (Remember, the load in this case is much different!) The signal you observe is the product of the gas gain of the proportional tube and the gain of the amplifier.

Increase the CO_2 flow rate to about 15 units and observe the pulse size for a few minutes. How much does the pulse height change? After you have observed the change in pulse size return to the flow rate you had before using.

If you look carefully at the oscilloscope trace you will notice structure in the pulse height spectrum below the main peak. It is due to an argon x-ray escape peak.

To really see what is going on, you need to make a pulse height spectrum. Connect the output of the preamp to a 575A pulse shaping amplifier, and set the gain to make a pulse height maximum of about 8 volts. Use the pulse height analyzer (PHA) to take a pulse height spectrum from ^{55}Fe. Fit the main peaks in the spectrum to get their position and full width at half-maximum.

For your report. What energy resolution does your proportional tube give for the ^{55}Fe signal? What energy corresponds to the Ar x-ray escape peak? At what energy *should* it appear?

Exercise 2 *From your fits and knowledge of the energetics of the detector, calculate the Fano factor for this detector, and compare it against the ones shown in the table on p. 131 in Leo.*

Now look at the PHA spectrum from one of the gamma sources (^{137}Cs, ^{22}Na,...) you are familiar with and discuss and explain the difference between its spectrum and the observed ^{55}Fe spectrum. (Hint: what is the difference in number of ionization events?)

The cathode pad

Make a "cathode pad" out of a small piece of brass covered with electrical tape. Place it underneath the prop tube towards the middle of the tube, and secure it with a piece of electrical tape. The brass itself should *not* be in contact with the plastic, but insulated by being completely wrapped with a layer of tape. Place the tube on the wooden part of the block. **For this part, the prop tube should *not* be lying on the Al foil covered side of the wood support block.**

Connect the other channel of the TRA1000 amplifier input to this pad and the ground to HV ground at the end of the tube with the available clip-lead cable.

Look at the outputs of both of the amplifier channels on the scope at the same time. (You will need to disconnect the cable to the 575A amplifier.) Set the scope channel sensitivities to the same volts/div. Make sure to terminate both channels with 50Ω. Observe and record the size and polarity of the signal as you move the source along the tube.

For your report. Answer the following questions concerning the operation of the cathode pad:

1. What causes the signal on the cathode pad? (Hint reread paragraph 2.)
2. Where, with respect to the position of the source, is the cathode pad signal strongest? Why?
3. Do you expect the cathode pad signal to be as big as the signal from the wire? Explain your answer.

When you are finished, make sure that the gas flow to your tube is turned off and that the high voltage is also turned off, along with all of the other electronics. You may take the tube with you as a souvenir, if you like.

References

[1] W.R. Leo Ch. 6, especially 6.1-6.5; also G. Knoll, Ch. 5, 6.

[2] G. Charpak, Annual Reviews of Nuclear Science, **20** p. 195, (1970).

[3] W. Blum and L. Rolandi, "Particle Detection with Drift Chambers", p. 124-132 (on reserve in Physics Library) QC787.D74.B58 1993.

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