Physics 198, Spring Semester 1999 Helmuth Spieler
Introduction to Radiation Detectors and Electronics

Problem Set 3: Due on Tuesday, 9-Feb-99 at begin of lecture.
Discussion on Wednesday, 10-Feb-99 at 12 – 1 PM in 347 LeConte.

1. A microchannel plate (MCP) consists of an array of capillaries, each of which forms a continuous electron multiplier structure. The inside of the capillary is coated to form a secondary electron emitting layer, which also exhibits the appropriate electric resistance to form a continuous voltage divider that sets up an acceleration field along the channel. In a typical device the individual channels are 10 µm diameter, with an open area ratio of ~50%, so there are 10^6 channels per cm^2. Operated at a voltage of 1000 V the gain is $5 \cdot 10^3$. The MCP is typically 0.6 mm thick and the resistance of each channel is about 10^{15} Ω. Metallization on the two faces of the MCP connects all channels in parallel, so only two connections are required, in addition to a collection electrode at the output.

   a) When first applying voltage to a microchannel plate, the first check is to monitor the supply current. Since MCPs must be operated in UHV to avoid contamination and random discharges, the DC current is also an indicator of the vacuum quality. For a 40 mm diameter MCP, what current draw do you expect at 1000 V?

   b) Assume a configuration where 1 photoelectron enters an individual channel. The gain remains constant up to an average signal current that is 10% of the standing current in a channel. What is the maximum counting rate per channel in the linear range? What is the maximum rate over the whole diameter of the MCP?

2. A 12-stage photomultiplier tube is operated at 2 kV for a gain of 10^7. This tube uses "conventional" SbKCs dynodes operated with 120 V potential difference between adjacent dynodes. Since the scintillator resolution is 7%, long term gain variations should be <1%. How stable must the power supply be to maintain this requirement?

3. Typically, 511 keV photons interacting in a NaI(Tl) scintillator provide about 3000 photoelectrons at the first dynode, yielding a theoretical resolution of 2% rms. Assume that non-uniformities in light collection and gain increase this resolution to 3%.

   a) What resolution do you expect for 30 keV x-rays? Express the resolution both as a percentage and as an energy spread, and compare with the result for 511 keV. In general, how does the resolution scale with energy?

   b) Replace the NaI(Tl) scintillator with a $PbWO_4$ crystal and compare the results for 30 and 511 keV with NaI(Tl).

4. A CsI(Tl) scintillator exposed to a ^{137}Cs source yields $7 \cdot 10^9$ electrons at the output of a photomultiplier tube.

   a) What is the peak anode current? Assume that the rise time is negligible.

   b) Replace the CsI(Tl) crystal by a BaF_2 scintillator. How does the peak anode current change?

5. In rummaging around the lab you find a silicon detector. Of course, the data sheet is nowhere to be found, but apparently the detector was designed for charged particle spectroscopy, so you have good reason to expect that it is less than a mm thick and has an “asymmetrical” junction.

   a) How can you determine the correct polarity of the bias voltage?

   b) You have a source of 1 MeV electrons. How can you determine the depletion voltage and the thickness of the detector?

   c) Assume that the detector is 300 μm thick with a depletion voltage of 120 V. What is the resistivity of the material?

   d) You’ve measured the diameter of the detector to be 20 mm. What is the capacitance at 0, 30, 60 and 120V?