1. Consider a 9-stage photomultiplier tube which is operating at a voltage of 1100V and has a bi-alkali photocathode. The secondary emission factor ($\delta$) at 1100V for this PMT is $\delta = 3.7$.

   a) How many electrons (on average) will be collected for every photoelectron emitted by the photocathode, assuming 100% collection efficiency?

   b) Suppose we observe a current of 83 nA at the output of the PMT when the PMT is illuminated by a light source emitting at 550 nm. How many photons are hitting the photocathode on average each microsecond? Recall that $1 \text{ C} = 6.24 \times 10^{18}$ electrons and use the QE chart above.
(question continued from page 1)

c) We can combine the PMT with a crystal of NaI doped with Thallium (Tl) to measure gamma ray energies. The gamma rays scatter electrons in the NaI(Tl) to create a shower which excites the crystal through ionizations. NaI(Tl) produces about 40,000 photons for each MeV of energy deposited in it. If we observe pulses of total charge 50 pC, what gamma ray energy is incident on the crystal? You may assume the scintillation photons are all 550 nm.

d) Given the number of photoelectrons, what width (uncertainty) do we expect for the energy? You may assume this is a Poisson process.

e) Suppose the HV drifts from 1100V to 1125V without our noticing. What type of error does this induce and how large is that error?
2. Consider the bolometer depicted above with a sensor area of 1 mm². The “cooling link” between the sensor and the thermal reservoir will carry $G = 1 \times 10^{-8}$ W/K.

a) What is the relationship between the flux $f$ in W/cm² and the power deposited on the bolometer, assuming 100% absorbance? (Please give your answer in symbols $P, f, A$)

b) What is the relationship between the flux and the temperature difference between the sensor and the reservoir?

c) Suppose the temperature difference between the reservoir and the sensor is 4 mK. What is the flux on the sensor in W/cm²? How many photons of $\lambda = 5$ mm per square centimeter per second does this correspond to?
3. Two different techniques for wavelength measurement of visible and near-visible photons were discussed in class: diffraction gratings and Fabry-Perot interferometers. In this question, you should consider these two techniques and determine which technique is more appropriate in each case and why.

a) If one is interested in real-time correlations between two wavelengths, is a Fabry-Perot interferometer or a diffraction grating more appropriate and why?

b) Which technique provides generally provides the best resolution?

c) If one is interested in ultraviolet spectroscopy, is a Fabry-Perot interferometer or a diffraction grating more appropriate and why? (Hint: A Fabry-Perot must have transmission through the mirrors.)

d) If the minimizing the side of the apparatus is critical, while maintaining resolution, is a Fabry-Perot interferometer or a diffraction grating more appropriate and why?