Problem 1 [Knoll Prob. 11.1]

From the values for intrinsic carrier densities, estimate the impurity levels (in parts per billion) that begin to change intrinsic silicon and germanium into doped materials at room temperature.

Problem 2 [Knoll Prob. 11.2]

Find the ratio of the number of charge carriers created in silicon by a 1 MeV proton to the number created by the same energy deposition in air.

Problem 3 [Knoll Prob. 11.3]

Calculate the mean value and variance in the number of electron-hole pairs created by the loss of 100 keV of particle energy in silicon.

Problem 4 [Knoll Prob. 11.4]

By what factor is the rate of thermal generation of electron-hole pairs in germanium reduced by cooling from room temperature to liquid nitrogen temperature (77 K)?

Problem 5 [Knoll Prob. 11.6]

Indicate the functional dependence of the following properties of a p-n junction on the magnitude of the applied reverse bias:

(a) Depletion width

(b) Capacitance

(c) Maximum electric field

Problem 6 [Knoll Prob. 11.7]

There is often a premium on fabricating detectors with the largest possible depletion width for a given applied voltage. Explain why starting with semiconductor material of the highest available purity enhances this objective.

Problem 7 **[Knoll Prob. 11.8]**

Find the bias voltage neccessary to create a depletion depth of 0.1 mm in a junction detector prepared from n-type silicon with 1000 Ω-cm resistivity.

Problem 8 **[Knoll Prob. 11.9]**

The primary alpha peak from a ^{241}Am calibration source was centered in channel number 461 of a multichannel analyzer when the alpha particles were collimated to be perpendicular to the surface of a silicon junction detector. The geometry was then changed to cause the alpha particles to be incident at an angle of 35^o to the normal, and the observed peak shifted to channel number 455. Assuming no zero offset in the MCA, find the dead layer thickness in units of alpha energy loss.

Problem 9 **[Knoll Prob. 11.10]**

Why does the typical energy resolution for surface barrier detectors worsen as the surface area of the detector increases?

Problem 10 **[Knoll Prob. 11.11]**

A totally depleted silicon detector with 0.1 mm thickness is operated with large overbias so as to saturate the carrier velocities everywhere within the wafer. Estimate the maximum electron and hole collection times.

Problem 11 **[Knoll Prob. 11.12]**

A partially depleted silicon surface barrier is operated with sufficient bias voltage to ensure that the depletion depth greatly exceeds the range of incident 5 MeV alpha particles. If used with a voltage-sensitive preamplifier, how much will the pulse amplitude change if the bias voltage changes by 5%?

Problem 12 **[Knoll Prob. 11.13]**

A 10-MBq source of alpha particles is located 10 cm in front of a silicon surface barrier detector. After what length of exposure time is radiation damage to the detector likely to become significant

Problem 13 [Knoll Prob. 11.14]

In a given heavy ion detector in which zero energy deposition corresponds to a channel zero in an associated multichannel pulse height analyzer, the 5.486 MeV alpha particles from ^{241}Am are recorded in channel number 116. If heavy ions of 21.0 MeV energy are recorded in channel 402, what is their pulse height defect?

Problem 14 [Knoll Prob. 11.15]

Sketch the expected differential pulse height spectra from a silicon surface barrier detector under the following conditions:

(a) Incident 5 MeV alpha particles, depletion depth of the detector greater than the alpha range

(b) On the same graph, the corresponding spectrum for a depletion depth of one-half the alpha range

(c) Again on the same graph, the spectrum with depletion depth as in part (a), but for the same alpha particles after they have passed through an absorber whose thickness is equal to one-half the alpha range in the absorber material.

Problem 15 [Knoll Prob. 11.16]

A planar germanium detector is operated at a temperature of 77 K with a nearly uniform electric field value of 1000 V/cm throughout its volume. Charges are created at a point within the detector volume by the interaction of a low-energy X-ray photon. Estimate the spatial broadening that will occur due to diffusion of the cloud of electrons as they drift over a distance of 1 cm.

Problem 16 [Knoll Prob. 12.2, 12.3]

A planar germanium detector with a 10-mm thick intrinsic region is operated with sufficient applied voltage to saturate the carrier velocities.

a) What is the approximated value of the required voltage?

b) What must be the minimum charge carrier lifetimes if no more than 0.1% of either holes or electrons are to be lost from any pulse?

c) This detector is operated with a pulse processing system that produces a peak with a 1.2 keV equivalent FWHM from a pulser input. Estimate the energy resolution of the detector-electronics systems for incident 140 keV gamma rays.

Problem 17 **[Knoll Prob. 12.3]**

The detector described above is operated with a pulse processing system that produces a peas with a 1.2 keV equivalent FWHM from a pulser input. Estimate the energy resolution of the detector-electronics systems for incident 140 keV gamma rays.

Problem 18 **[Knoll Prob. 12.4]**

The Compton edge in a gamma-ray spectrum recorded with a germanium detector for a given isotope lies at an energy of 1.6 MeV. Find the energy of the incident gamma rays and the equivalent energy of the Compton edge in a sodium iodide detector.

Problem 19 **[Knoll Prob. 12.5]**

Why are escape peaks generally more prominent in germanium detector gamma-ray spectra compared with sodium iodide detectors?

Problem 20 **[Knoll Prob. 12.6]**

A germanium detector has a photopeak efficiency of 40% relative to that of a standard 7.62 cm $\times$ 7.62 cm NaI(Tl) scintillator. Find the counting rate for the 1.333 MeV peak for a ^{60}Co point source of 150 kBq activity at a distance of 40 cm.

Problem 21 **[Knoll Prob. 12.7]**

Assuming that a charge collection is complete and that electronic noise is negligible, find the expected energy resolution (in percent) of a germanium detector for the 0.662 MeV gamma rays from ^{137}Cs.

Problem 22 **[Knoll Prob. 12.8]**

For incident 2.10 MeV gamma rays, at what energy does the peak appear in the spectrum from a pair spectrometer?

Problem 23 **[Knoll Prob. 13.1]**

Give two reasons why the X-ray escape peak is less intense in silicon detectors compared with germanium detectors.

Problem 24 [Knoll Prob. 13.2]

Estimate the maximum charged collection time for a 4-mm thick planar Si(Li) detector operated at 2000 V.

Problem 25 [Knoll Prob. 13.3]

What must be the energy resolution (in percent) for a Si(Li) detector if it is to resolve separately the K-characteristic X-rays from copper and zinc?

Problem 26 [Knoll Prob. 13.4]

What physical effects cause the detection efficiency of Si(Li) detectors to drop off at low (less than 5 keV) incident X-ray energies?

Problem 27 [Knoll Prob. 13.5]

By using an NaI(Tl) well counter with absolute peak efficiency of 83%, a net of 146835 counts was recorded under the 122 keV photopeak from a ^{57}Co source over a 15-min live time. The same source was then placed 10 cm from the face of an Si(Li) detector with 200 mm^2 surface area and a spectrum recorded over a 60-min counting period. If 730 counts were recorded under the 6.4 keV X-ray peak, what is the efficiency of the Si(Li) detector at this energy?

Problem 28 [Knoll Prob. 13.6]

Find the statistical limit for the energy resolution of a Si(Li) detector for the 59,5 kEV gamma rays from ^{241}Am . Compare the result with the corresponding value for a HPGe detector at the same energy. What would the value be for a silicon drift detector?

Problem 29 [Knoll Prob. 13.7]

Estimate the thickness of the following semiconductor materials that result in 50% of all incident 662 keV gamma ray photons undergoing at least oneinteraction: Si, Ge, CdTe and HgI_2. In each case, also estimate the fractions of the inital interactions that are photoelectic absorption and Compton interaction

Problem 30 [June 2012]

A 1.27 MeV photon undergoes two successive Compton scatters in the active volume of a Germanium detector before it escapes. In the first scattering, the photon loses 540 keV and in the second 210 keV

- How many compton electrons are produced in each of the scatterings?
- What is the energy of these electrons?
- What is the total number of e-h pairs generated in each interaction?
- Discuss whether the detector will record the photon's passage as one or two events

Data: w=2.96 eV for Ge

Problem 31 [January 2014]

A thin layer of ^{241}Am with a total activity of 2 MBq is deposited on the surface of a silicon surface barrier detector. The ^{241}Am emits α with an energy of 5.480 MeV. Calculate:

a] The charge (in C) of the electrons generated in each pulse

b) The current (in A) induced by these electrons

c) If the Fano factor of the detector is $F = 0.15$, what is the energy resolution we will obtain?

Problem 32 [June 2014]

For the quality control of a proton beam, a water phantom equipped with two diodes is used. These diodes are read in current mode with a sampling rate of 4 Hz.

The first diode, which is used as a reference and remains fixed, intercepts 0.1% of the total beam intensity. The energy loss of each proton in this diode is 4 MeV. The second diode, which is placed in the centre of the irradiated area, intercepts 1% of the beam and each proton loses 2 MeV in the diode.

a) What is the current measured by each of the diodes as a function of beam intensity?

b) What are the variances of these currents?

In many cases, what we are interested in is the ratio between the two currents.

c) Calculate the ratio between the current of the second diode compared to the first according to the intensity of the beam.

d) What is the error of this ratio? Give the numerical value of this error for beam intensities of 10^4 p/s and 10^8 p/s

Problem 33 Excess Noise Factor [January 2017]

In several photodetectors, the charge multiplication gives rise to an exponential pulse height distribution for single primary charges:

$$f(x) = ae^{-ax} \quad x: \text{ charge signal produced by one primary charge}$$

a) What is the mean multiplication factor?

b) What is the variance of the multiplication factor?

c) What is the Excess Noise Factor?