Problem 1 [Grupen Prob 5.1]

A Geiger-Mueller counter (dead time 500 μs) meausres in a strong radiation field a count rate of 1 kHz. What is the dead-time corrected true rate?

Problem 2 [Grupen Prob 7.4]

60 keV X-rays from a ^{241}Am source are to be measured in a proportional counter. The counter has a capacity of 180 pF. What kind of gas gain is required if the amplifier cinnected to the anode wire requires 10 mV at the input for good signal-to-noise performance? The average energy to porduce an electron-ion pair in the argon filled counter is $\omega = 26$ eV. What is the intrinsic energy resolution of the 60 keV line? The Fano factor for argon is F=0.17.

Problem 3 [Knoll Prob 5.1]

Calculate the charge represented by the positive ions (or free electrons) created when a 5.5 MeV alpha particle is stopped in helium. Find the corresponding saturated current if 200 alpha particles per second enter the helium-filled ion chamber.

Problem 4 [Knoll Prob 5.2]

The following data were taken from an ion chamber under constant irradiation conditions

Voltage (V)	Current (pA)
10	18.72
20	19.41
50	19.93
100	20.12

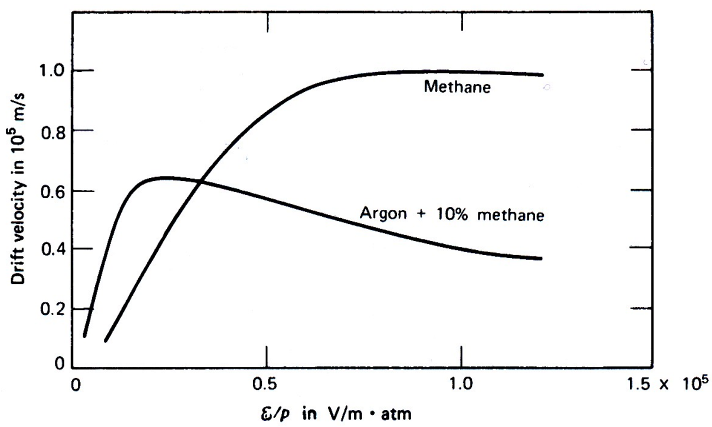
Find the saturated ionization current. What minimum voltage must be applied in order to reach a current within 0.5% of saturation?

Problem 5 [Knoll Prob 5.3]

An air-equivalent pocket chamber having a capacitance of 75 pF is initially charged to a voltage of 25 V. If the active volume contains 50 cm^3 of air at STP, what value of gamma-ray exposure will reduce the chamber voltage to 20 V?

Problem 6 [Knoll Prob 5.4]

An ion chamber is constructed using parallel plate electrodes with a spacing of 5.0 cm. It is filled with pure methane gas at a pressure of 1 atm and operated at an applied voltage of 1000 V. From the data given in the figure below, calculate the maximum electron collection time.



Problem 7 [Knoll Prob 5.5]

A parallel plate ion chamber has an associated capacitance of 250 pF. It is charged initially to a voltage of 1000 V, exposed to a gamma ray flux for a period of 30 min, at which time a second voltage measurement indicates a value of 850 V. Calculate the average current that would have bee measured over the exposure period under these conditions.

Problem 8 [Knoll Prob 5.7]

A free-ionization chamber of the type sketched in the figure below has a sensitive volume of very small dimensions. Estimate the minimum, electrode spacing if true compensation is to be maintained up to a maximum gamma-ray energy of 5 MeV.

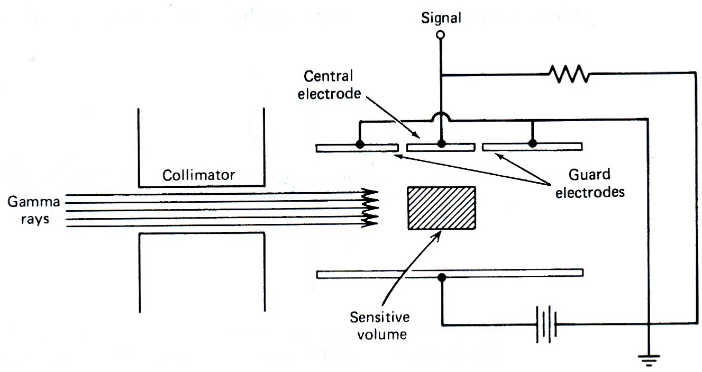


Figure 5.10 The free-air ionization chamber. Because secondary electrons created in the sensitive volume cannot reach the electrodes before stopping, compensation is required only in the dimension parallel to the incident radiation.

Problem 9 [Knoll Prob 5.8]

The average beta particle energy emitted by ^{14}C is 49 keV. Calculate the saturated ion current if 150 kBq of the isotope in the form of CO_2 gas is introduced into a large volume ion chamber filled with pressurized argon.

Problem 10 [Knoll Prob 5.9]

Calculate the minimum current that must be measured if a 1-liter ion chamber is to be used as a gamma-ray survey meter down to dose rates of 0.5 mR/h (35.8 pC/kg·s).

Problem 11 [Knoll Prob 5.10]

A parallel plate ion chamber with 150 pF capacitance is operated in electron sensitive mode. Calculate the pulse amplitude expected from 1000 ion pairs formed 2 cm from the anode, if the total spacing between the plates is 5 cm.

Problem 12 [Knoll Prob 5.11]

A small air-filled ionization chamber of fixed interior dimensions is located 10 m from a 1 MeV gamma-ray source. Imagine that the walls of the chamber are made of aluminum and are of variable thickness. Neglecting background radiation, plot the relative ionization current from the chamber as a function of wall thickness for the two conditions listed below:

(a) The experiment is performed in a normal air-filled laboratory.

(b) The experiment is performed in a satellite and the surronding space is essentially a vaccuum.

Problem 13 [Knoll Prob 5.12]

An air-equivalent ion chamber is constructed using aluminum walls. What is the minimum thickness of these walls if compensation is to be maintained up to a maximum gamma-ray energy of 10 MeV?

Problem 14 [Knoll Prob 5.13]

An air-filled ion chamber is operated at a pressure of 3 atm and a temperature of 100^{o}C. Its active volume is 2500 cm^3, find the saturated ion current corresponding to a gamma-ray exposure rate of 100 pC/kg·s

Problem 15 [Knoll Prob 5.14]

A pocket chamber is constructed with an internal volume of 10 cm^3 and a capacitance of 20 pF. If the smallest voltage change that can be sensed is 50 mV, calculate the minimum gamma-ray exposure to which the pocket chamber will be sensitive.

Problem 16 [Knoll Prob 5.15]

Using estimates for the mobility of ions and electrons in air, estimate the ratio of the slopes of the two segments of the rise of the pulse in the figure below.

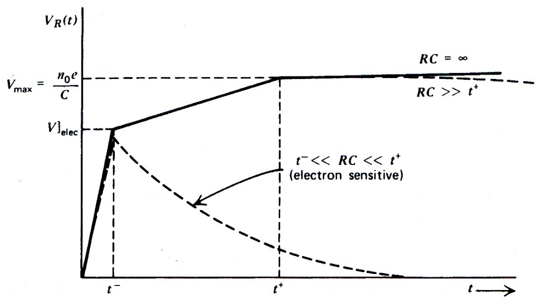


Figure 5.16 Output pulse shape $V_R(t)$ for various time constants RC in the schematic diagram of Fig. 5.15.

Problem 17 [Knoll Prob 6.1]

Assuming ω=26.2 eV/ion pair and the Fano factor F=0.17 for argon, find the mean and the expected standard deviation in the number of ion pairs formed by the absorption of 1 MeV of radiation energy.

Problem 18 [Knoll Prob 6.3]

(a) A proportional counter with anode radius of 0.003 cm and cathode radius of 1.0 cm is filled with P-10 gas at 1 atm. Using the Diethorn parameters, find the voltage required to achieve a gas multiplication factor of 1000.

(b) At the same voltage, by what factor would the multiplication change if the anode were twice as large?

(c) With the original anode radius, by waht factor would the multiplication change if the cathode radius were doubled?

Problem 19 [Knoll Prob 6.4]

A windowless flow proportional counter is used to detect 5 MeV alpha particles that are totally stopped in the fill gas. The tube has an anode radius of 0.005 cm, a cathode radius of 5.0 cm and is filled with P-10 gas at 1 atm. Estimate the amplitude of the voltage pulses from the counter for an applied voltage of 2000V and a collection capacitance of 500 pF.

Problem 20 [Knoll Prob 6.7]

A given voltage-sensitive preamplifier requires a minimum input pulse amplitude of 10 mV for good signal/noise performance. What gas multiplication factor is requires in an argon filled proportional counter with 200 pF capacitance if 50 keV X-rays are to be measured?

Problem 21 [Knoll Prob 6.8]

A cyclindrical proportional tube has an anode wire radius of 0.003 cm and a cathode radius of 2.0 cm. It is operated with an applied voltage of 2000 V. If a minimum electric field of 1.0 MV/m is required to initiate gas multiplication, what fraction of the internal volume of the tube corresponds to the multiplication region?

Problem 22 [Knoll Prob 7.2]

Predict the efect each of the following changes would have on the observed starting voltage for a Geiger-Mueller tube if all other parameters remain the same:

(a) Doubling the diameter of the anode wire.

(b) Doubling the fill gas pressure

(c) Doubling the trace concentration of the quench gas

Problem 23 [Knoll Prob 7.4]

Estimate the voltage at which a counter with anode radius of 0.003 cm, cathode radius of 1.0 cm and filled with P-10 gas at 1 atm enters the Geiger region of operation. Assume that three excited atoms are formed for every ion pair in a typical avalanche and the the subsequent de-excitation photons have a probability of 10^{-5} of creating an additional avalanche.

Problem 24 [Knoll Prob 7.8]

In a given counter gas operated at a pressure of 0.5 atm the mobility of a free electron is 1.5×10^{-4} (m/s)·(m/V)·atm. The threshold electric field for the onset of avalanche formation is 2×10^{6} V/m. If this gas is used in a cylindrical tube with anode radius of 0.005 cm and cathode radius of 2 cm, calculate the drift time of an electron from the cathode to the multiplying region for an applied voltage of 1500 V.

Problem 25 [Knoll Prob 7.9]

A Geiger-Mueller counting system has a resolving time of 350 μs. Find the true rate at which the losses due to this dead time amount to half of all the true events (one could argue that this rate is roughly the maximum rate at which the tube can give reasonably reliable reuslts). Use both the paralyzable and non-paralyzable models to obtain two different predictions that probably bracket the actual value.

Problem 26 [Knoll Prob 7.10]

The G-M tube of the previous problem is operated in "time-to-first-count" mode to extend its upper counting rate limit. The voltage to the tube is suppressed for a period of 900 μs following each recorded count to allow its full recovery. Assume that the time required to switch the high voltage on is 0.3 μs, and that the onset of the Geiger discharge can be measured to a much smaller timing uncertainity.

(a) The limit on counting rate now is reached when the probability that a true event occurs during the switching time is no longer small. Calculate the true rate for which this probability reaches 5%.

(b) At this limiting rate, what is the mean time to first count following swithching of the voltage?

(c) A survey instrument is based on operating in this mode over a 2-s period to measure the true rate. At the same limiting rate, what is the percent uncertainty in this measurement due to counting statistics?

Problem 27 [Tsoulfanidis Prob 5.4]

In a cylindrical gas counter with a central wire radius equal to 25 μm, outer radius 25 mm, and 1000 V applied between anode and cathode, what is the distance from the center of the counter at which an electron gains enough energy in 1 mm travel to ionize helium gas? (Take 23 eV as the ionization potential of helium).

Problem 28 [Tsoulfanidis Prob 5.5]

A GM counter with a mica window is to be used for measurement of ^{14}C activity. What should the thickness of the window be if it is required that at least 90% of the ^{14}C betas enter the counter?

Problem 29 [Tsoulfanidis Prob 5.6]

What is the minimum pressure required to stop 6 MeV alphas inside the argon atmosphere of a spherical gas counter with 25 mm radius? Assume the alpha source is located at the center of the counter.

Problem 30 [Tsoulfanidis Prob 5.7]

What is the ratio of the saturation ionization currents for a chamber filled with He vesus one filled with CH_4 (other things being equal)?

Problem 31 [Tsoulfanidis Prob 5.9]

Calculate the maximum value of the positive ion time for a cylindrical counter with a cathode radius of 19 mm and a central anode radios of 25 μm. The high voltage applied is 1000 V, the pressure of the gas is 13.3 kPa, and the mobility of the ions is 13.34 (m/s·Pa)/(V/m)

Problem 32 [Turner Prob 10.9]

An alpha particle source is fabricated into a thin foil. Placed first in a 2π gas-flow proportional counter, it shows only a single pulse height and registers 7080 counts/min (background negligible). The source is next placed in 4π geometry in an air ionization chamber operated under saturation conditions, where it produces a current of 5.56×10^{-12} A. Assume that the foil stops the recoil nuclei following alpha decay but absorbs a negligible amount of energy from the alpha particles.

(a) What is the activity of the source?

(b) What is the alpha particle energy?

(c) Assume that the atomic mass number of the daughter nucleus is 206 and calculate its recoil energy.

Problem 33 [Turner Prob 10.10]

A ^{210}Po source is placed in an air ionization chamber, and a saturatuion current of 8×10^{-12} A is observed. Assume that the ionization is due entirely to 5.30 MeV alpha particles stopping in the chamber. How many stop per second?

Problem 34 [Turner Prob 10.11]

An ionization chamber is simultaneously bombarded by a beam of 8×10^6 helium ions per second and a beam of 1×10^8 carbon ions per second. The helium ions have an initial energy of 5 MeV, and the carbon ions have an initial energy of 100 keV. All ions stop i the chamber gas. For the helium ions, $\omega = 36$ eV/ion pair; for the carbon ions $\omega = 48$ eV/ion pair. Calculate the saturation current.

Problem 35 [Turner Prob 10.12]

A source emits 5.16 MeV alpha particles which are absorbed at a rate of 842 per minute in the gas of a parallel-plate ionization chamber. The saturation current is 3.2×10^{-13} A. Calculate the ω value of the alpha particles in the gas.

Problem 36 [Turner Prob 10.14]

A saturation current of 2.79×10^{-14} A is measured with a parallel-plate ionization chamber in a radiation field. The chamber contains air ($\omega = 34$ eV/ion-pair) at 20^{o}C and 752 torr.

(a) What is the rate of energy absorption in the chamber?

(b) If the chamber has a sensitive volume of 750 cm^3, what is the dose rate in the air in J/(kg s) (=Gy/s)?

Problem 37 [Turner Prob 10.15]

A parallel plate ionization chamber is being designed to work with air ($\omega = 34$ ev/ion pair) at STP. When the dose rate in the chamber is 10.0 mGy/h, the saturation current is to be 10^{-11} A. What volume must the chamber have?

Problem 38 [Turner Prob 10.17]

What is the ratio of the pulse heights from a 1-MeV proton ($\omega = 30$ eV/ion pair) and a 1-MeV carbon nucleus ($\omega = 40$ eV/ion pair) absorbed in a proportional counter?

Problem 39 [June 2010]

The signal induced by the passage of a particle through an ionization chamber at a distance x_0 from the anode as a function of time is:

$$V_r(t) = -\frac{Nq}{Cd}(v^- + v^-)t$$

(a) Calculate the arrival time of electrons at the anode (T^-) and of the ions at the cathode (T^+)
d=10 cm, x_0=3cm, $v^- \sim 5$cm/μs, $v^+ \sim 3$cm/ms

(b) Explain and draw the time evolution of the signal in the case case that $RC >> T^-, T^+$

Problem 40 [June 2012]

To check the stability of a ^{12}C beam with an intensity of 6×10^{10} nuclei/s, an ionisation chamber read in current mode is used. The diameter of the ionisation chamber is such that it intercepts only 25% of the beam. The energy loss of the carbon nuclei in the ionisation chamber is 396 keV and the average energy to generate an electron-ion pair in the ionisation chamber gas is 35 eV

- What is the current measured by the ionisation chamber?
- What is the relative error of this measurement?

Problem 41 [June 2013]

Calculate the maximum ion collection time for a GM (cylindrical geometry) filled with Ar with a pressure of 100 mmHg if the operating voltage is 1000 V. This time gives an idea of the dead time. mobility of the ions for Ar = 1040 (torr)(cm/s)/(V/cm)
$\vec{E}(r) = \frac{1}{r}\frac{V_0}{\ln\left(\frac{b}{a}\right)}$
anode radius: $a = 0.01$ cm
cathode radius: $b = 1$ cm

Problem 42 Production of Electron-Ion Pairs [September 2015]

Compute the total and primary number of charge pairs produced in a mixture of 90% CO_2 and 10% CH_4

Gas	I_e (eV)	w (eV/ip)	dE/dx (keV/cm)	n_p (ip/cm)	n_t (ip/cm)
H_2	15.4	37	0.34	5.2	9.2
He	24.6	41	0.32	5.9	7.8
N_2	15.5	35	1.96	10	56
O_2	1.2	31	2.26	22	73
Ne	21.6	36	1.41	12	39
Ar	15.8	26	2.44	29	94
Kr	14.0	24	4.60	22	192
Xe	12.1	22	6.76	44	307
CO_2	13.7	33	3.01	34	91
CH_4	10.8	28	1.48	46	53

Problem 43 X-ray photons [January 2018]

To measure a 100 keV photon beam we use a cylindrical ionisation detector. The photons enter the detector through a 100 μm thick aluminum window and are attenuated in the 6 cm thick bed of the filling gas (CO_2) kept at he atmospheric temperature and pressure. The photons surviving the interactions leave the detector through another 100 μm thick aluminum window.

a) Estimate the percentage photons absorbed in the ionization detector.

b) What fraction of photons interact via Compton? and via photoelectric effect?

c) Make an estimation of the signal generated. Assume that there is just one photon interaction in the detector and that the total readout capacitance is 10 nF.

Data: $\mu_{Al} = 0.1704$ cm^2/g
$\mu_C = 0.1514$ cm^2/g
$\mu_O = 0.1551$ cm^2/g
$\rho_{Al} = 2.699$ g/cm^3
$\rho_{CO_2} = 1.833 \times 10^{-3}$ g/cm^3
$\omega_{CO_2} = 33$ eV/pair

Problem 44 Spherical proportional counter [January 2018]

In 2005, Giomataris and Vergados (NIM A530,330) proposed the use of spherical vessels for rare event detection in neutrino physics. This proportional counter is formed by an spherical vessel of radius R_1 and an internal sphere of radius R_2. High voltage can be applied among the two spheres and a detection system can be installed in the inner sphere. The vessel should be filled with mix of Ar(90%) and CO_2(10%) with pressures that can go up to 10 to 40 bar.

The electric field in the region between the two spheres is:

$$E(r) = \frac{V_0}{r^2}\frac{1}{1/R_2 - 1/R_1} \qquad V = V_0\frac{1/R - 1/R_1}{1/R_2 - 1/R_1}$$

and the capacitance

$$C = \frac{4\pi\varepsilon_0}{1/R_2 - 1/R_1}$$

The breakdown voltage, the voltage at which the gas starts the avalanche is $\frac{E}{p} \simeq 10\frac{V}{mPa}$. One of such spherical counters have the following characteristics:

$$R_1 = 1.3 \text{ m}$$
$$R_2 = 1.4 \text{ cm}$$
$$V_0 = 15 \text{ kV}$$
$$P = 20 \text{ bar}$$

At which distance will the avalanche region starts?

Problem 45 Ionization chamber

To control the stability of a proton beam with a nominal intensity of 2×10^8 nuclei/s we use an ionization chamber read in current mode. The diameter of the chamber intercepts just 50% of the beam, the energy loss of protons in the chamber is 11 keV and the mean energy to produce an electron-ion pair in the the gas inside the chamber is 30 eV.

a) What is the current measured by the ionization chamber?

b) What is the relative error of this measurement?