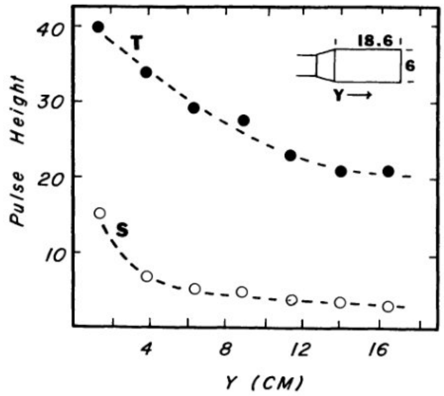
Problem 1 [Fernow Prob. 7.3]

Estimate the attenuation length of the test scintillation of the figure

Figure 7.5 Relative light collection from a test scintillator using (T) totally reflecting surfaces and (S) vacuum-deposited aluminum surface. The inset shows the test counter dimensions in centimeters. (After D. Crabb, A. Dean, J. McEwen, and R. Ott, Nuc. Instr. Meth. 45: 301, 1966.)



Problem 2 [Fernow Prob. 7.5]

Find the mean number of collected photoelectrons corresponding to a detection efficiency of 99.9%. What is the probability of observing half this number of photoelectrons?

Problem 3 [Fernow Prob. 7.6]

Estimate how many photons are produced in a 1-cm thick plastic scintillator by (a) 1-GeV/c protons, (b) 100-MeV/c protons, and (c) 10-GeV protons.

Problem 4 [Knoll Prob. 8.1]

Calculate the scintillation efficiency of anthracene if 1 MeV of particle energy loss create 20300 photons with average wavelength 447 nm.

Problem 5 [Knoll Prob. 8.2]

Assuming a decay constant of 230 ns, how much time is required for a NaI(Tl) scintillation event to emit 99% of the total light yield?

Problem 6 [Knoll Prob. 8.3]

Assumint that the scintillation light pulse in each case is a pure exponential, find the ratio of the maximum brightness (rate of photon emission) of pulses generated by equal electron energy deposition in NaI(Tl) and anthracene.

Problem 7 [Knoll Prob. 8.4]

Make a selection between a typicla inorganic scintillator (i.e. NaI(Tl)) and a typical organic scintillator (i.e. a plastic scintillator on the basis of the following principles:

a) Speed of response

b) Light output

c) Linearity of light with deposited energy

d) Detection efficiency for high-energy gammas

e) Cost

Problem 8 [Knoll Prob. 8.6]

Which scintillation material is most efficient at converting the energy of a 2 MeV electron into light?

Problem 9 [Knoll Prob. 8.8]

Scintillation light is emitted isotropically within a slab of plastic scintillator. If other dimensions of the slab are assumed to be infinite, calculate the fraction of light that scapes from either slab surface.

Problem 10 [Knoll Prob. 8.9]

The dark-eyed adapted human may be able to detect as few as 10 visible photons as a single flash. Will an observer with pupil diameter of 3 mm be able to see individual scintillation events caused by a 1 MeV beta particle in NaI(Tl) while viewing the surface of the scintillator at a distance of 10 cm?

Problem 11 [Knoll Prob. 8.10]

a) A 1 MeV fast electron passes across the 0.3 mm diameter of a plastic fiber scintillator. Estimate the deposited energy.

b) Assuming a reasonable scintillation efficiency, calculate the corresponding number of scintillation photons created alog the track.

c) The refractive index for the core and the cladding are 1.58 and 1.49 respectively, and the fiber has an attenuation length of 2 m. Estimate the number of scintillation photons arriving at one end of the fiber that is 1 m from the point of interaction

Problem 12 [Knoll Prob. 9.1]

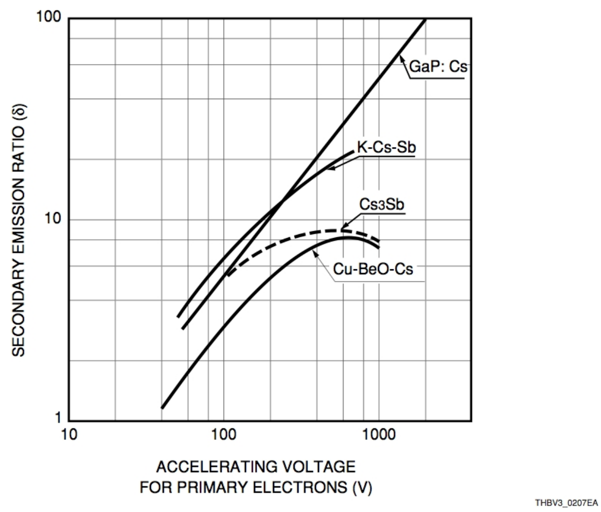
Calculate the long-wavelength limit of the sensitivity of a photocade layer with work function of 1.5 eV.

Problem 13 [Knoll Prob. 9.2]

Find the transit time for an electron between typical dynodes in a PM tube if the interdynode spacing is 12 mm and the potential difference is 150 V per stage. For symplicity, assume a uniform electric field.

Problem 14 [Knoll Prob. 9.3]

Using the date plotted in the figure, find the total applied voltage necessary for a PM tube with a six-stage multiplier using GaP(Cs) dynodes to achieve an electron gain factor of 10^6.



Problem 15 [Knoll Prob. 9.4]

The dark current from a PM tube with electron gain of 10^6 is measured to be 2 nA. What is the correspondig electron emission rate from the photocathode?

Problem 16 [Knoll Prob. 9.5]

The gain per dynode δ of a 10-stage PM tube varies as $V^{0.6}$ where V is the interdynode voltage. If the tube is operated at an overall voltage of 1000V, how much voltage fluctuation can be tolerated if the gain is not to change by more than 1%?

Problem 17 [Knoll Prob. 9.6]

The decay time for scintillations in NaI(Tl) is 230 ns. Negelcting any time spread introduced by the PM tube, find the maximum value of the voltage pulse amplitude for anode circuit constants of 10, 100 and 1000 ns. Express your answer as a ratio to the amplitude that would be observed for an infinite time constant. What is the minimum value of the time constant if this ratio is to be at least 0.9?

Problem 18 [Knoll Prob. 9.7]

A current pulse of the following shape flowz ont a parallel RC dircuit:

$$i(t) = I \qquad 0 < t < T$$

$$i(t) = 0 \qquad t > T$$

Find the general solution $V(t)$ for the voltage appearing across the circuit, assuming $V(0) = 0$. Sketch the solution on the two limits:

a) $RC >> T$

b) $RC << T$

Problem 19 [Knoll Prob. 9.8]

Calculate the amplitude of the signal pulse expected from a NaI(Tl)-PM tube under the following circumstances:

Radiation energy loss:	1.2 MeV
Light collection efficiency:	70%
Photocathode quantum efficiency:	20%
PM tube electron gain:	10^5
Anode capacitance:	100 pF
Anode load resistance:	$10^5\Omega$

Problem 20 [Knoll Prob. 9.10]

The bandgap energy in silicon at room temperature is 1.11 eV. Calculate the longest wavelength of light that is energetically capable of exciting an electron across this gap to create an electron-hole pair in a photodiode.

Problem 21 [Knoll Prob. 9.11]

A scintillator absorbs an incident flux of 5 MeV alpha particles that totals 10^6 particles/s. The scintillation efficiency for these particles is 3%, and the average wavelength of the emitted light is 420 nm. If the scintillation is coupled to a photodiode wiht an average quantum efficiency of 75% for the scintillation light and the ligth collection efficiency is 80%, estimate the expected signal from the photodiode when operated in current mode.

Problem 22 [Knoll Prob. 9.12]

Estimate the acceleration voltage required for a hybrid photomultiplier tube using a silicon diaode to have a charge gain of 5000.

Problem 23 [Knoll Prob. 10.1]

A gamma-ray photon after Compton scattering through an angle of 90^o has an energy of 0.5 MeV. Find its energy before the scattering.

Problem 24 [Knoll Prob. 10.2]

A 2 MeV gamma-ray photon is incident on a detector, undergoes two sequential Compton scatterings, and then scapes. If the angles od scattering are 30^o and ector? 60^o, repectively, how much total recoil electron scattering is deposited in the detector.? Does the answer change if the sequence of the scattering angle is reversed?

Problem 25 [Knoll Prob. 10.3]

Find the maximum energy that can be deposited by a 1 MeV gamma-ray photon if it undergoes two successive Compton scattering events and then escapes the detector.

Problem 26 [Knoll Prob. 10.4]

Estimate the time that separates two successive gamma-ray scattering interactions that are 3 cm apart in sodium iodide. Compare with the characteristic decay time that is generated in the same material.

Problem 27 [Knoll Prob. 10.5]

The cross section for photoelectric, Compton and pair production interactions is sodium iodide at 2 MeV are in the ratio 1:20:2, respectively. Will the pulse height spectrum from 2 MeV gamma rays incident on a sodium iodide scintillator give a peak-to-total ratio of less than, more than, or about equal to 1/23?

Problem 28 [Knoll Prob. 10.6]

If the energy resolution of a particular NaI(Tl) scintillation detector is 7% for ^{137}Cs gamma-rays (0.662 MeV), estimate its energy resolution for the 1.28 MeV gamma rays from ^{22}Na.

Problem 29 [Knoll Prob. 10.7]

The mass attenuation coefficient of NaI at 0.5 MeV is 0.955 cm^2/g. Find the intrinsic total efficiency of a slab detector 0.5 cm thick at this energy. If the photofraction is 40% at the same energy, what is the intrinsic peak efficiency?

Problem 30 [Knoll Prob. 10.8]

a) Find the energy of the Comptom edge for the 1.17 MeV gamma rays from ^{60}Co.

b) Calculate the backscatter peak energies corresponding to incident gamma rays of 1,2 and 3 MeV.

Problem 31 [Knoll Prob. 10.9]

Listed below are a number of parameters of interest in gamma-ray spectroscopy using scintillation detectors:

(a) Density of the detector medium.

(b) Kinetic energy required to create a scintillation photon in the crystal

(c) Average atomic number (Z-value) of the detector medium.

(d) Geometry of the source-detector system.

(e) Gain of the photomultiplier tube.

(f) Quantum efficiency of the photocathode in the photomultiplier.

(g) Gain of hte amplifier used between the detector and pulse analysis system.

(h) Fraction of light generated in the crystal that reaches the photocathode of the PM tube (light collection efficiency).

Identify those parameters from this list that have a major influence on the detector intrinsic peak efficiency. Repeat, but now identify those that have a major influence on energy resolution.

Problem 32 **[Knoll Prob. 10.10]**

Calculate the pulse amplitude from the anode pf a PM tube used with a NaI(Tl) scintillator under the following conditions:
a 1-MeV electron loses all its energy in the scintillator,
the light collection efficiency to the photocathode is 50%,
the average quantum efficiency of the photochatode is 20%
80% of the photoelectrons are collected at the first dynode.
Assume that the PM-tube has 10 stages with a multiplication factor δ=2.5 per stage. The anode load resistance is 100 $k\Omega$, and the anode capacitance 100 pF.

Problem 33 **[Knoll Prob. 10.11]**

A particular radioisotope emits two coincident gamma rays, each with 100% yield per decay, with no angular correction between the photon directions. A sample is placed 10 cm from the surface of a 5 cm radius cylindrical detector along its axis. The intrinsic peak efficiency of the detector for γ_1 is 50%, and for γ_2 it is 30%.

(a) If the sample activity is low enough so that chance coincidences are negligible, calculate the ratio of the counts under the sum peak in the recorded pulse height spectrum to the counts under the γ_1 full-energy peak.

(b) Calculate the rate at which events are recorded in the sum peak if the source activity is 100 kBq. For a detector resolving time of 3 μs, what additional rate should be expected from chance coincidences between γ_1 and γ_2?

Problem 34 **[Knoll Prob. 10.12]**

Estimate the range of a 1-MeV electron in sodium iodide. From your answer, calculate the pertage of the total voulum of a 5.08 cm $\times$ 5.08 cylindrical crystal that lies near enough to the surface so that electron escape is possible.

Problem 35 [Knoll Prob. 10.13]

A radioisotope source is known not to emit any gamma-ray photons with energy of 511 keV, but a peak is observed at this position in the recorded gamma-ray spectrum. Give two possible origins for this peak.

Problem 36 [Knoll Prob. 10.14]

If the energy resolution of a scintillator is 8.5% at 662 keV, find the standard deviation (in energy units) of the Gaussian curve that would be a fit to the photopeak at that energy.

Problem 37 [Knoll Prob. 10.15]

Why are materials with low atomic number often perferred as scintillators for electron spectroscopy, while the opposite is true for gamma-ray spectroscopy?

Problem 38 [Knoll Prob. 10.16]

Explain the major advantage of liquid scintillation counting when applied to low-energy beta emitters compared with conventional solid scintillation detectors.

Problem 39 [Tsoulfanidis Prob. 6.1]

If the dead time of a detector using a scintillation is 1 μs, what is the gross counting rate that will result in a loss of 2 percent of the counts?

Problem 40 [Tsoulfanidos Prob. 6.2]

A typical dead time for a scintillation detector is 5 μs. For a gas counter, the corresponding number is 200 μs. If a sample counted with a gas counter results in 8 percent loss of gross counts due to dead time, what is the corresponding loss in a scintillation counter that records the same gross counting rate?

Problem 41 [Tsoulfanidos Prob. 6.3]

A parallel beam of 1.5 MeV gammas strikes a 25 mm thick NaI crystal. What fraction of these gammas will have at least one interaction in the crystal?

Problem 42 **[Tsoulfanidos Prob. 6.4]**

What is the range of 2 MeV electrons in a plastic scintillator? Assume that the composition of the scintillator is $C_{10}H_{11}$ ($\rho = 1.02 \times 10^3$ kg/m^3)

Problem 43 **[Tsoulfanidos Prob. 6.6]**

A phoswich detector consists of a 1-mm thick NaI(Tl) scintillator coupled to a 25 mm thick CsI(Tl) scintillator. A 0.1 mm thick beryllium window protects the NaI(Tl) crystal. If the detector is exposed to a thin parallel beam of 150 keV x-rays and 1.5 MeV α rays, what are the fractions of interactions of each type of photon in each scintillator?

Problem 44 **[June 2010]**

(a) Calculate the amplitude of the pulse in the anode of a PM coupled to a plastic scintillator (w=100 eV/photon) under the following conditions:

- an electron of 0.7 MeV which loses all its energy in the scintillator
- 60% of the generated photons arrive at the photocathode
- The quantum efficiency of the photocathode is 23%.
- The PM has 12 dynodes: the first three have a multiplication factor of 4, and the remaining nine of 3.4.
- The resistance and capacitance at the anode are 80 kΩ and 90 pF.

(b) Calculate the energy resolution of this detector.

(c) If the readout electronics introduce an energy indetermination of 15 keV, what is the total energy resolution for 0.7 MeV electrons? And for 2.8 MeV electrons?

Problem 45 **[June 2011]**

A NaI scintillator is bombarded with ionising radiation resulting in an ionisation rate of 1.5 MeV/s. The scintillation photons are detected by a photomultiplier. If 15% of the photons are lost before reaching the photocathode, the quantum efficiency of the photocathode is 20%:

- Calculate the current in the first dynode of the photocathode

b) Calculate the gain of the PM if the secondary electron emission rate from the dynodes is $delta = 4$ and the total number of dynodes is $n = 10$

c) Calculate the current in the anode of the photomultiplier

Data:

- NaI produces 40000 photons per MeV

Problem 46 [June 2012]

Compute the relative scintillation efficiency of YAP to NaI(Tl).

Data	NaI	YAP
Light yield	38000 γ/MeV	18000 γ/MeV
Light yield	38000 γ/MeV	18000 γ/MeV
λ_{max}	415 nm	370 nm

Note: YAP (Yttrium Aluminum Perovskite) is an inorganic scintillator used for Fast X-Ray Spectroscopy. Due to its very fast decay time can be operated with high counting rates (several MHz). It is an excellent choice instead of NaI (max counting rate of 100's kHz) for X-Ray and low gamma ray applications.

Problem 47 [January 2013]

Consider a detector for γ radiation consisting of an LSO scintillator coupled to a photomultiplier with a gain of 10^5 and a photocathode quantum efficiency of 25%. The light collection efficiency of the whole system is 50%. The signal is taken from the PMT anode with a 50Ω coaxial cable and fed to an oscilloscope. If we observe γ radiation of 1 MeV.

a) What is the scintillation efficiency of the LSO?

b) Find the equation that gives the current pulse as a function of time. Assume that the signal rise time is 0 and that there is only a fast component

c) What is the maximum voltage that would be observed in the oscilloscope if the input impedance of the oscilloscope is 50Ω? What if the input impedance is $1M\Omega$?

Data: LSO: yield 28000 photons/MeV.
Decay time: 40 ns $\lambda = 420$ nm

Problem 48 [June 2013]

We have a spectrometer made up of an anthracene crystal and a photomultiplier with 10 dynodes. The crystal has an efficiency of 15 photons per keV of energy deposited. The photocathode generates one photoelectron for every 10 photons that arrive and each dynode produces 3 secondary electrons. Estimate the height of the pulse produced if a 1 MeV electron lost all its energy in the crystal. The capacitance of the output circuit is 1.2×10^{-10} F.

Problem 49 Mesure de $\Upsilon(1S)$ et $\Upsilon(2S)$][January 2015]

In a high-energy physics experiment, we try to measure the masses of the two particles $\Upsilon(1S)$ and $\Upsilon(2S)$. Theory tells us that these have masses of $9460MeV$ and $10020MeV$ respectively and that they can decay into two electrons.

At these energies, we can approximate $m_e \approx 0$ and we also assume that the Υ are produced at rest. Therefore, we try to measure electrons of energy $E_1 = 4730MeV$ and $E_2 = 5010MeV$.

To achieve this, lead tungstate scintillators ($PbWO_4$) are used which have a very fast response ($\tau < 15ns$), are radiation resistant and have a luminosity of $L = 200\gamma/MeV$ in which the electrons will lose all their energy. Tests showed that the fraction of scintillation light arriving at the photomultiplier was $F = 50\% \pm 1\%$, the quantum efficiency of the photocathode is $\epsilon_{QE} = 20\%$, the PM formed by 10 dynodes offers a total gain of $G = 1000$ and the readout circuit is an RC system with $R = 1k\Omega$ and $C = 100pF$. The reading of the data finally adds an error of 1% on the measurement (one can note $f = 1 \pm 1\%$).

a) What is the height of the pulse produced by the electrons of the two energies considered E_1 and E_2?

b) If the power supply to the dynodes was perfectly stable, what would be the resolution of the E_2 peak at the output of the reading system?

c) If we want to be able to clearly discern the two peaks ($E - delta > FWHM_{max}$), how stable should the dV/V power supplies be?

Problem 50 Scintillation counter [January 2017]

A plastic scintillator of length L and attenuation length λ_{SC} has photon detectors (PMTs, SiPM, ...) directly coupled to both sides. We consider that both photon detectors have the same characteristics: efficiency, geometry, etc.

a) If a passing particle produces a normalized pulse height of 100 mV on the left and 60 mV on the right, find the position of the particle along the counter.

b) How is the apparent position of the particle changed if there are light guides of length $L/4$ on each side with attenuation length $\lambda_{LG} = 2\lambda_{SC}$

Problem 51 Energy resolution [January 2018]

Compute the energy resolution of a gamma radiation of 1 MeV measured by:

a) Plastic scintillator (w=100 eV)

b) NaI scintillator (w=25 eV)

Consider that both are coupled to PM with a quantum efficiency of 20% and the scintillators are big enough to stop all the energy.

Problem 52 Scintillation detection [January 2022]

A charged ionizing particle losses on average about 2.5 MeV of its energy in a 2 cm thick scintillator, and about 80 eV of deposited energy is needed to produce one photon of scintillation light pulse. The scintillator is optically coupled through a light guide to a photomultiplier.

(a) What is the light yield of the scintillator? Assume the wavelength of the scintillation photons $\lambda = 450$ nm.

(b) The light collection efficiency of 15%, what is the number of photons arriving to the photocathode?

(c) The quantum efficiency of the photocathode is 20%, how many photoelectrons will be produced?

(d) The photomultiplier have 10 dynodes, each of them with a $\delta = 3$, how many electrons will arrive to the readout anode?

e) The anode capacitance and resistance are $C = 50$pF and $R = 10^4\Omega$. Sketch in a Voltage vs time plot the signal output of the photomultiplier indicating the maximum voltage and the shape of the signal.

Problem 53 Scintillation detection [September 2022]

A charged ionizing particle losses on average about 2.0 MeV of its energy in a 2 cm thick scintillator, and about 100 eV of deposited energy is needed to produce one photon of scintillation light pulse. The scintillator is optically coupled through a light guide to a photomultiplier.

(a) What is the light yield of the scintillator? Assume the wavelength of the scintillation photons $\lambda = 400$ nm.

(b) The light collection efficiency of 10%, what iss the number of photons arriving to the photocathode?

(c) The quantum efficiency of the photocathode is 25%, how many photoelectrons will be produced?

(d) The photomultiplier have 12 dynodes, each of them with a $\delta = 3$, how many electrons will arrive to the readout anode?

e) The anode capacitance and resistance are $C = 50$pF and $R = 10^4\Omega$. Sketch in a Voltage vs time plot the signal output of the photomultiplier indicating the maximum voltage and the shape of the signal.