Alpha Particle Spectroscopy: Bragg Curve and Range in Air

Monoenergetic alpha particles from a ^{210}Po source are passed through an air absorber and their energy is subsequently measured with a silicon surface barrier detector. The measured alpha energy for each of a number of air absorber thicknesses is used to determine the energy dependence of the rate of energy loss, as well as the range of 5.3 MeV alphas in air.

Bring a thumb drive to class and use it to save the spectra you collect with the Maestro software.

Background Readings

Solid-State Detectors, Melissinos and Napolitano, pp 344 - 354
Energy Loss, Leo, pp 21 - 34
Silicon Diode Detectors, Leo, pp 233 - 234
NIST Data Tables, https://physics.nist.gov/PhysRefData/Star/Text/ASTAR.html

Procedures

1. Adjust the distance between the source stage and the silicon detector to be somewhat larger than the known range of 5.3 MeV alphas in air at STP. Measure this distance, as well as the diameter of the opening in the white plastic detector mask. Caution: DO NOT TOUCH the detector surface. Record the room temperature and humidity daily.

2. Install a ^{210}Po source (with the source well facing up!) and evacuate the chamber to its minimum pressure. Over a period of about 60 seconds, *very slowly* apply a +30 volt bias to the detector. When you are done for the day you should reduce this bias to zero – also over a time of about 60 seconds. The detector preamplifier is *extremely* vulnerable to rapid changes in the bias voltage! Use the oscilloscope to inspect the pulses first from the E output of the model 142 preamplifier, and then from the model 571 amplifier's unipolar output. Set the amplifier's pulse shaping constant to 6 μs, and adjust the gain so that the amplitude of the unipolar signals of interest is near 8 volts. Use the multi-channel analyzer (MCA) and the MAESTRO software to collect a source spectrum for a known live time. Save this histogram.

3. To measure the MCA pedestal channel: Connect the attenuated output signal from the model 419 pulser to the test input of the preamp. Put the attenuation switches in the OUT (down) position, and set the NORMALIZE dial to 10 (fully clockwise). Now, watching either

on the scope or on the displayed MCA spectrum, adjust the PULSE HEIGHT control until the pulser peak appears to the right of the alpha peak. Keep the pulser peak below channel 500 in the MCA spectrum.

Collect a spectrum while the attenuators are set to: 1 (all down), 2, 4 (2 x 2), 5, and 10. You can collect all of these peaks within just one spectrum, which you will save at the end. When finished, switch the pulser relay to the OFF position.

4. Collect Po-210 source spectra over a wide range of chamber pressures. Start with an evacuated chamber, and then increase the pressure in steps. Record the live time, the peak centroid channel, the peak FWHM in channels, and the approximate peak yield (area) for each spectrum. Continue increasing the pressure until you can no longer estimate the peak centroid channel. Hint: The real "action" in these data occurs at relatively low alpha energy, so this is where you should collect the largest number of spectra. When you have completed your data collection each day, be sure to evacuate the chamber.

The electronic gauge measures the absolute pressure in the chamber in units of Torr. The dial measures the vacuum relative to local atmospheric pressure, in units of inches of mercury. The atmospheric pressure at any time in Lexington is available on the web.

Analysis

1. Alpha particles from the decay of ^{210}Po are emitted isotropically. Use this fact to calculate the fraction of emitted alphas which will enter the aperture of your detector. With this value, and with your measured source count rate, determine the overall activity of your source in units of μCi. Assume that your detector is 100% efficient, so that every alpha entering its aperture is recorded in the peak response.

2. The relationship between channel number in the MCA and detected energy is linear and of the form

$$\mathrm{C} = a + b\mathrm{E}$$

where C is the peak centroid channel, E is the alpha energy in keV, and a and b are constants. If we had several sources of various energies, we could collect a spectrum with each one and do a least-squares fit to determine the best-fit values of a and b. However, in this case we have only 2 pieces of information to use to make our calibration: we know the peak channel corresponding to the maximum alpha energy, and we know the pedestal channel (a) from the spectrum we collected with various pulser attenuations. So, first determine the pedestal from your data, and then evaluate b, the channels per energy.

Knowing these values, you can now readily convert any channel in your MCA spectrum into an alpha energy.

3. Analyze the spectra you have collected at each pressure setting by finding the energy of the peak centroid, E_p, in keV, the peak FWHM in keV (simply divide the FWHM in channels by b, the number of channels per keV), and the count rate under the peak, R, in counts per minute. For each pressure setting, also calculate the absorber thickness of air, in mg/cm^2. To simplify your analysis, tabulate your results using the format shown below. Do not put this large table into your paper. Instead, pick data from a small "representative" region of maybe just four or five adjacent pressures to present.

τ_p (mg/cm^2)	E_p (keV)	FWHM (keV)	R (counts/sec)
...			

Make a plot of E_p *vs* τ_p for all of your data. Extrapolate your results to determine an estimate of the range of 5.3 MeV alpha particles in air, in units of mg/cm^2.

4. The simplest way to determine the rate of energy loss is to recognize that your set of n data points comprises a set of n-1 energy intervals. Each of these intervals will be assigned an average energy, E_m and thickness, τ_m. In both cases, these values are the computed means of their respective endpoint values. This method clearly works best when the intervals between measurements are "small." Prepare a table using the format shown below which lists the n-1 numerical values for E_m and τ_m. For each of these intervals, include the calculated average rate of energy loss,

$$\frac{dE}{d\tau} = \frac{\Delta E_p}{\Delta \tau_p}$$

Do not put this large table into your paper. Instead, show only the results which are based on the data given in the short table discussed above, in step 3.

τ_m (mg/cm^2)	E_m (keV)	dE/dτ (keV/mg/cm^2)
...		

Make a plot of your full set of results showing the magnitude of dE/dτ as a function of energy. Overlay a smooth curve showing the Bethe-Bloch prediction.

Some issues to address in your paper

1. What can be learned about energy straggling from your data?

2. As the thickness of the absorber is increased, do you observe a significant loss of alpha particles at the detector? Can you explain, or at least characterize, your observations?

Methods

Absorber Thickness

In common usage we think of an object's thickness as a linear measurement. But in physics we often combine this linear measurement with the object's volume density to define a thickness as an *areal density,* using units of mass per area. We do this because we are often interested in quantifying the number of interactions that occur between a beam of particles and a target material on an atomic or nuclear scale. The areal density determines the number of atoms "seen" by each particle in an incident beam. For example, elemental carbon is available in a broad range of volume densities, so merely specifying the linear thickness of a carbon target does not in itself determine the number of carbon atoms encountered by an incident particle, whereas its areal density does.

The areal density, τ, of a sample is defined in terms of its volume density, ρ, and linear thickness, L:

$$\tau(\mathrm{g/cm^2}) = \rho(\mathrm{g/cm^3}) \times L(\mathrm{cm}) \tag{1}$$

The absorber of interest in this project is air. In order to determine the value of τ for an air absorber, we must first determine the density of the air. Since air (approximately 80% N_2 and 20% O_2) typically contains water vapor, the overall density of humid air, ρ, has one component due to dry air, and another due to the water vapor:

$$\rho = \rho_d + \rho_v \tag{2}$$

The density of dry air, $\rho_d(\mathrm{kg/m^3})$, at absolute temperature $T(\mathrm{K})$, and partial pressure $P_d(\mathrm{N/m^2})$ is given by:

$$\rho_d = \frac{P_d}{R_d T} \tag{3}$$

where R_d is the specific gas constant for dry air. Similarly, the density of the water vapor

$$\rho_v = \frac{P_v}{R_v T} \tag{4}$$

The gas constants for dry air and water vapor have the values

$$R_d = 287.058 \ \mathrm{J/Kg \cdot K} \tag{5}$$
$$R_v = 461.495 \ \mathrm{J/Kg \cdot K} \tag{6}$$

The total absolute pressure P is the sum of the partial pressures for dry air and water vapor,

$$P = P_d + P_v \tag{7}$$

This overall pressure is a measured quantity, but we must find the individual values of P_d and P_v. To do this we first note that the partial vapor pressure is simply determined by the relative humidity, ϕ (a number < 1), and P_{sat}, the saturation vapor pressure,

$$P_v = \phi \times P_{sat} \tag{8}$$

The saturation pressure is determined by only the temperature, and is given by the unwieldy form,

$$P_{sat} = 610.78 \times 10^{\frac{7.5T-2048.625}{T-35.85}} \quad (\mathrm{N/m^2}) \tag{9}$$

Knowing the air temperature and humidity, one uses eqn. 9 to calculate the saturation pressure, and then the partial pressure of the water vapor using eqn. 8. The partial pressure of dry air is determined with eqn. 7. The conversion between mks pressure units and Torr (the unit used by our electronic gauge) is

$$1 \text{ Torr} = 133.3224 \text{ N/m}^2 \tag{10}$$

Other possibly useful definitions:

$$1 \text{ N/m}^2 = 1 \text{ Pa (Pascal)} \tag{11}$$

Standard temperature and pressure (STP): 293.15 K; 101325 Pa (1 atmosphere); $\phi = 0$.

Energy Loss of Charged Particles

When a charged particle such as an electron, proton, or alpha particle passes through any material, it loses energy due to its interactions with the constituent atoms. In general, the most important component of this interaction is of an electromagnetic origin, but the details of the interaction depend upon the mass, charge, and speed of the incident particle as well as the electronic structure of the target material. Typically, we can treat the various energy loss mechanisms for a relatively light charged particle, such as an electron, as distinct from the processes which govern energy loss by a heavy particle such as a proton or alpha particle. This is because in all cases the particle's dominant loss mechanism is due to its interaction with atomic electrons, and the kinematics of this process are usually very different for light and heavy incident beams. Our focus here is on the loss mechanism for relatively heavy charged particles like protons and alpha particles.

As an alpha particle transits an absorber, its charge (+2) interacts with the surrounding electrons, creating ionization in the material. In some cases the released electrons can have sufficient energy to create additional ionization, but more typically the alpha simply leaves a localized trailing "wake" of electron-ion pairs. The alpha energy is typically in the MeV range, but the ionization energy of the absorber is usually in the 10's of eV. Thus, a single alpha will create many thousands of electron-ion pairs before it loses all of its kinetic energy and is brought to rest. Also, as long as the alpha is moving rapidly, its trajectory is little affected by its individual interactions with the absorber, but as the alpha slows and nears the end of its range, its path becomes more random as the more significant effects due to individual collisions accumulate. This randomness in energy loss and angular deflection is referred to as "straggling." Because of straggling the range of an alpha particle is not a well-defined quantity; often the range is specified as the distance traveled in an absorber while the alpha slows to a particular low energy where the effects of straggling become important.

The quantum-mechanical calculation of the rate of energy loss of a charged particle in an absorber (target) was first done by Hans Bethe in 1930, and was later supplemented by Felix Bloch in 1933. The result is now referred to as the Bethe-Bloch equation. Over the years additional corrections have been added to the original formula, but these are generally small, and are not considered here.

We make the following definition of symbols:

e	Electron charge
Z_p	Projectile charge (units of $\|e\|$)
Z_t	Target atomic number
m_e	Electron mass
m_p	Projectile mass
r_e	Classical electron radius
ρ	Target density (mass/volume)
N	Target density (atoms/volume)
E	Projectile kinetic energy
B	Atomic stopping number
I	Mean ionization energy
x	Linear distance

Then, for a "heavy" non-relativistic projectile, the energy loss depends explicitly on the projectile energy, E, and is given by the Bethe-Bloch formula

$$-\frac{dE}{dx} = 2\pi r_e^2\ (m_e c^2)^2\ Z_p^2 N(\frac{m_p}{m_e})(\frac{B}{E}) \tag{12}$$

The units of this calculated loss rate are easily evaluated,

$$\text{(energy/length)} \sim \text{length}^2 \times \text{energy}^2 \times 1/\text{length}^3 \times \text{(mass/mass)} \times \text{(1/energy)} \tag{13}$$

The loss rate can be converted to energy loss per unit of thickness given as an areal density using

$$\frac{dE}{d\tau} = \frac{1}{\rho}\frac{dE}{dx} \tag{14}$$

The stopping number, B, appearing in the Bethe-Bloch formula is a pure number. This term also depends on the projectile energy, and is calculated using

$$B = Z_t \; ln(\frac{4m_e E}{m_p I}) - 0.90 \tag{15}$$

For an air absorber, the mean ionization energy, I, is 32.5 eV. The value of Z_t for air which is used in equation 15 is the weighted mean of the values for each of the constituent atoms.

The web site of the National Institute of Standards and Technology (NIST) contains energy loss data for a variety of particles transiting a variety of materials. In particular, the energy loss rate for alpha particles in dry air is available in tabulated form at

https://physics.nist.gov/PhysRefData/Star/Text/ASTAR.html

Select *Air, Dry* from the drop-down menu at the top of the form, and check the box labeled *Total Stopping Power*. Below the plot is a listing of the calculation. You can simply cut and paste this table into a spreadsheet, and then edit it to preserve only the first column (Energy) and fourth column (Total Stopping Power) results. We are primarily interested in these results in the range of energies from 0.1 to 6 MeV.

Alternately, equations 12 and 15 can be easily programmed in MATLAB or PYTHON. Using the loop function, the calculation can be done over a broad range of closely-spaced energies and the results plotted showing $dE/d\tau$ on the y-axis, and E on the x-axis. When applied to alpha particles slowing down in air, one typically chooses units of keV/mg/cm^2 for the loss rate. Alternately, the loss rate can be plotted as a function of distance in the absorber, x. The resulting figure is then called the Bragg Curve.

The overall range of a projectile particle which is initially at energy E_0 can be computed from the known rate of energy loss

$$R(E_0) = \int_0^{E_0} \frac{dE}{-dE/d\tau} \tag{16}$$

The integral is computed over a span of projectile energies extending from E_0 down to zero energy. The range computed with equation 16 is given in units of areal density, which is easily converted to linear distance at STP conditions using the known density of the absorber.

You can obtain the calculated range for an alpha particle of specified initial energy starting with your MATLAB or PYTHON results for the energy loss. Just modify the program to apply the trapzoidal rule to determine the integral numerically. (This is a rewarding experience. Try it!)

Silicon Surface Barrier Detectors

The detector used in this project is composed of a circular wafer of n-doped silicon with a thin layer of gold evaporated onto one of its faces. Particles enter the detector by passing through the gold face. The detector is easy to use, but a microscopic understanding of how it operates involves some details of solid state physics which are fairly complicated. For this reason we will only summarize the detector's operation. If you are interested in further details, check out the Background Reading list at the top of the ToDo page.

Alpha particles have charge +2, and when they travel through silicon they create an ionization trail. The average energy required to create a single electron-ion pair in silicon is approximately 3 eV, so a 5 MeV alpha creates over a thousand such pairs while coming to rest.

You should use the power supply to apply a bias of 30 volts to your detector. The bias supply is connected to electrodes which are attached to each face of the crystal, creating an electric field which extends to a depth of a few hundred microns in the crystal volume. This is called the depletion region of the detector. As an alpha particle passes through the depletion region, the charges which are liberated by ionization are swept to opposite poles of this small, capacitor-like object, and this produces an electrical pulse. The amplitude of the pulse is proportional to the alpha's energy loss within the detector's depletion region.

Connect either the E or T output of the preamplifier (they provide the same signal) to your oscilloscope. To get started, set the time scale for 50 μs per horizontal division, and the vertical scale for 50 mV per cm. An alpha interacting in the silicon will produce a pulse with a sharp rising edge (short rise time), and an exponentially-decaying falloff lasting a few hundred μs.

Do not touch the gold face of the detector, and always increase or decrease the bias voltage at a slow rate, taking perhaps 30 - 60 seconds to either apply or remove the full voltage. At the end of each lab period leave the detector bias turned off, and the chamber under good vacuum.

tained from polonium alpha particles of different energies (after attenuation in air).

Another recent type of solid-state detector, called *p-i-n* (positive-intrinsic-negative material), consists of a layer of intrinsic crystal placed between *p*-type and *n*-type material. Having the advantage of a much longer sensitive volume, it holds better promise for high-energy particle detection.†

5.3 Range and Energy Loss of Po^{210} Alpha Particles in Air

In Section 3 a description has been given of the method of obtaining an estimate of the range (and hence energy) of Po^{210} alpha particles in air, by means of a crude ionization chamber. With solid-state detectors, it is possible to improve on these measurements, as well as to study the rate of energy loss of the alpha particles as a function of their energy.

A collimated Po^{210} source and the detector are both placed in an evacuated vessel at a fixed distance of 15 cm, as shown in Fig. 5.39. Then air is allowed into the vessel, and as a function of the pressure we measure

(a) The number of particles counted in the detector
(b) The pulse height distribution of the output signals, namely, the energy of the alpha particles when they reach the detector

In measurements of type (a), the *same* number of alpha particles should be reaching the detector until the pressure is raised to the point where the amount of material (gm/cm² of air) between source and detector is equal to the range of the alpha particles; beyond that pressure the counting rate should abruptly fall to zero. Note that since the relative position of source and detector is not altered, the solid angle $\Delta\Omega$ does not change, and the

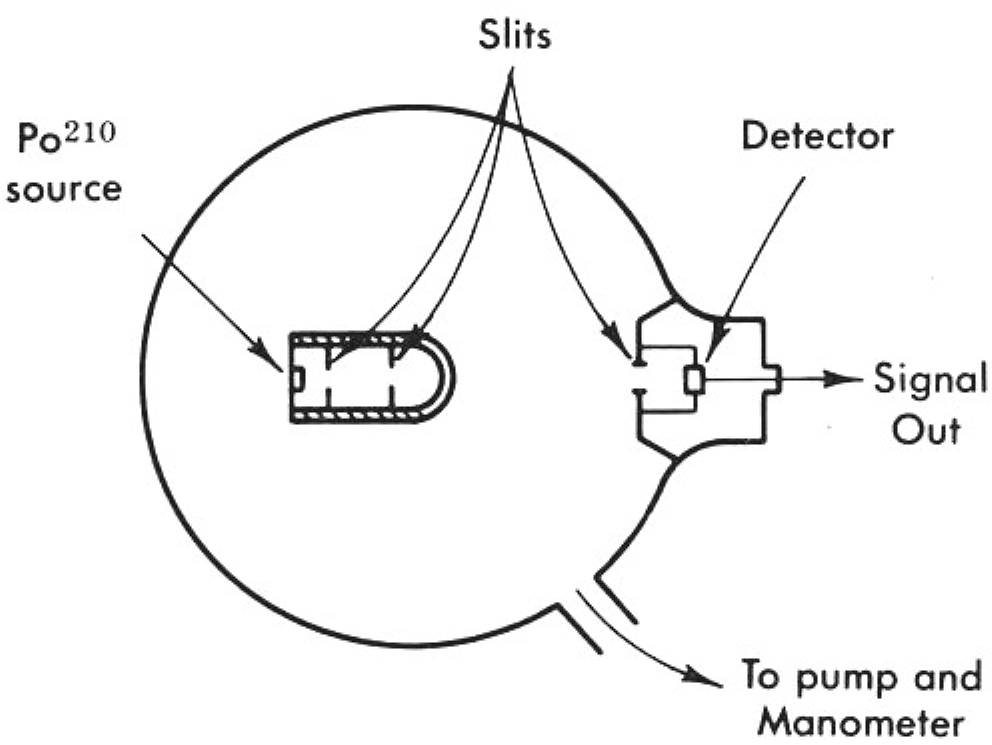


Fig. 5.39 Arrangement for the measurement of the range in air of Po^{210} alpha particles. Note mounting of the solid-state detector and source inside an evacuated chamber (see also Fig. 6.4a).

† For more details see J. M. Taylor, *Semiconductor Particle Detectors*. London and Washington, D. C.: Butterworth, 1963; also consult the current literature.

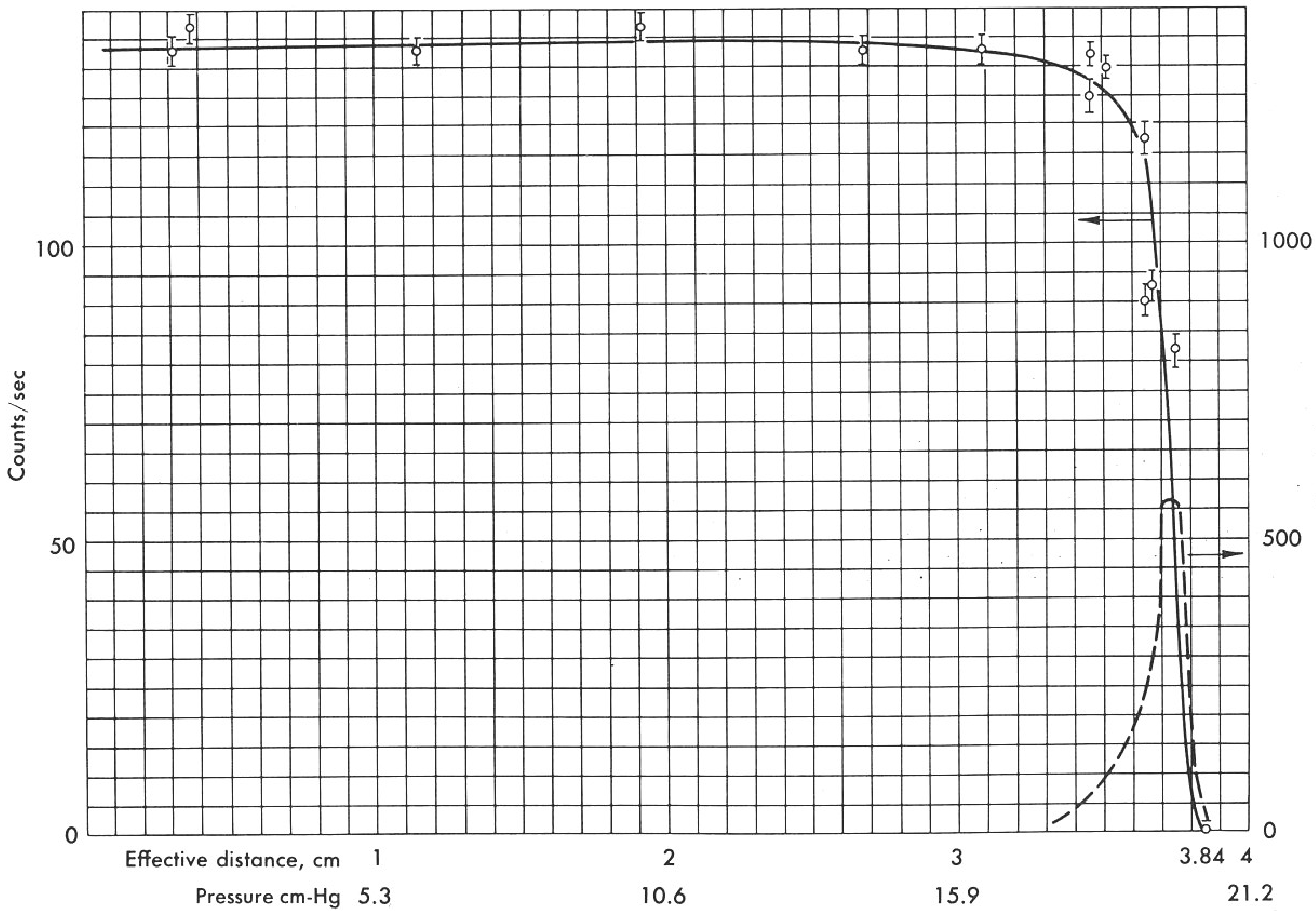


FIG. 5.40 Data on the number of counts from a Po^{210} alpha source reaching the solid-state detector as a function of the air pressure in the experimental chamber. Note that the corresponding effective distance in centimeters of air at stp is also included. The dotted curve is the derivative of the solid line; it indicates the "straggling" in the range of the alpha particles.

only variation arises from the increase in multiple scattering; this, in turn, may result in some loss of particles from the beam.

These considerations are indeed borne out by the results obtained by a student† and shown in Fig. 5.40. Here the ordinate to the left gives the counts per second while the abscissa gives the pressure of air in centimeters of mercury, or, equivalently, the effective distance of air at stp. The dotted curve to the right is the derivative with respect to distance of the counting curve and gives the range (and so-called range straggling) of Po^{210} alpha particles. We obtain a mean range of

$$R = 3.72 \pm .06 \text{ cm}$$

and an extrapolated range

$$R = 3.82 \pm .06 \text{ cm}$$

which might indicate some systematic discrepancy from the accepted value for the extrapolated range of 3.93 cm.

Turning now to the measurements of type (b), Fig. 5.41 shows the distribution of the detector pulse heights as obtained with the single channel discriminator (described in connection with the scintillation counter). Each peak corresponds to a different pressure, and we thus note that the alpha particles reach the detector with progressively less energy when they have traversed more gm/cm² of air. We set the pulse height obtained in vacuum equal to the full energy of the Po^{210} alpha particle, namely, 5.25 MeV, and use the linear characteristic of the solid-state detector to obtain

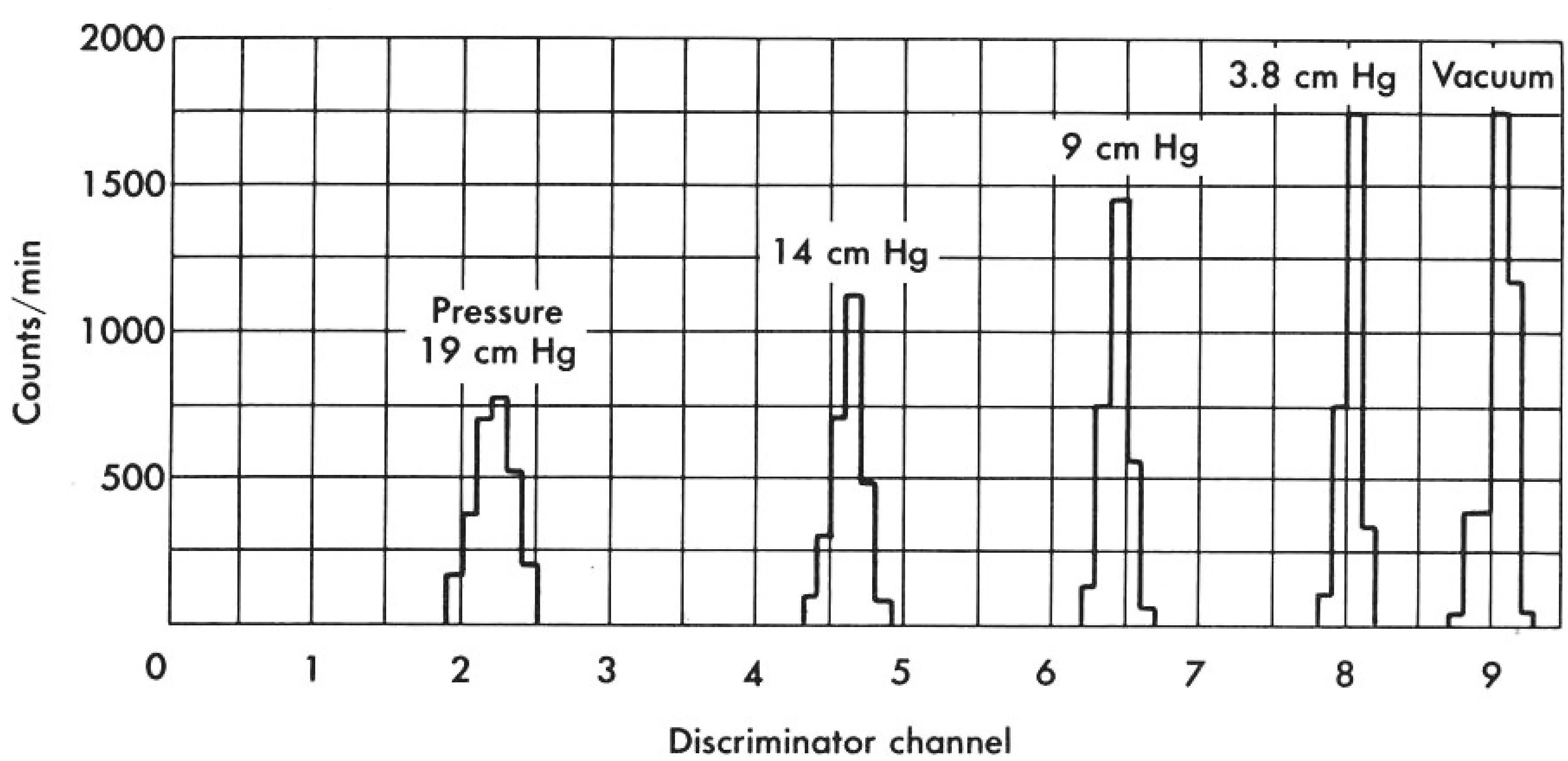


FIG. 5.41 Distribution of output pulse height of the solid-state detector for five different pressures. Note the gradual decrease of the energy of the alpha particle.

† K. Douglass, class of 1964.

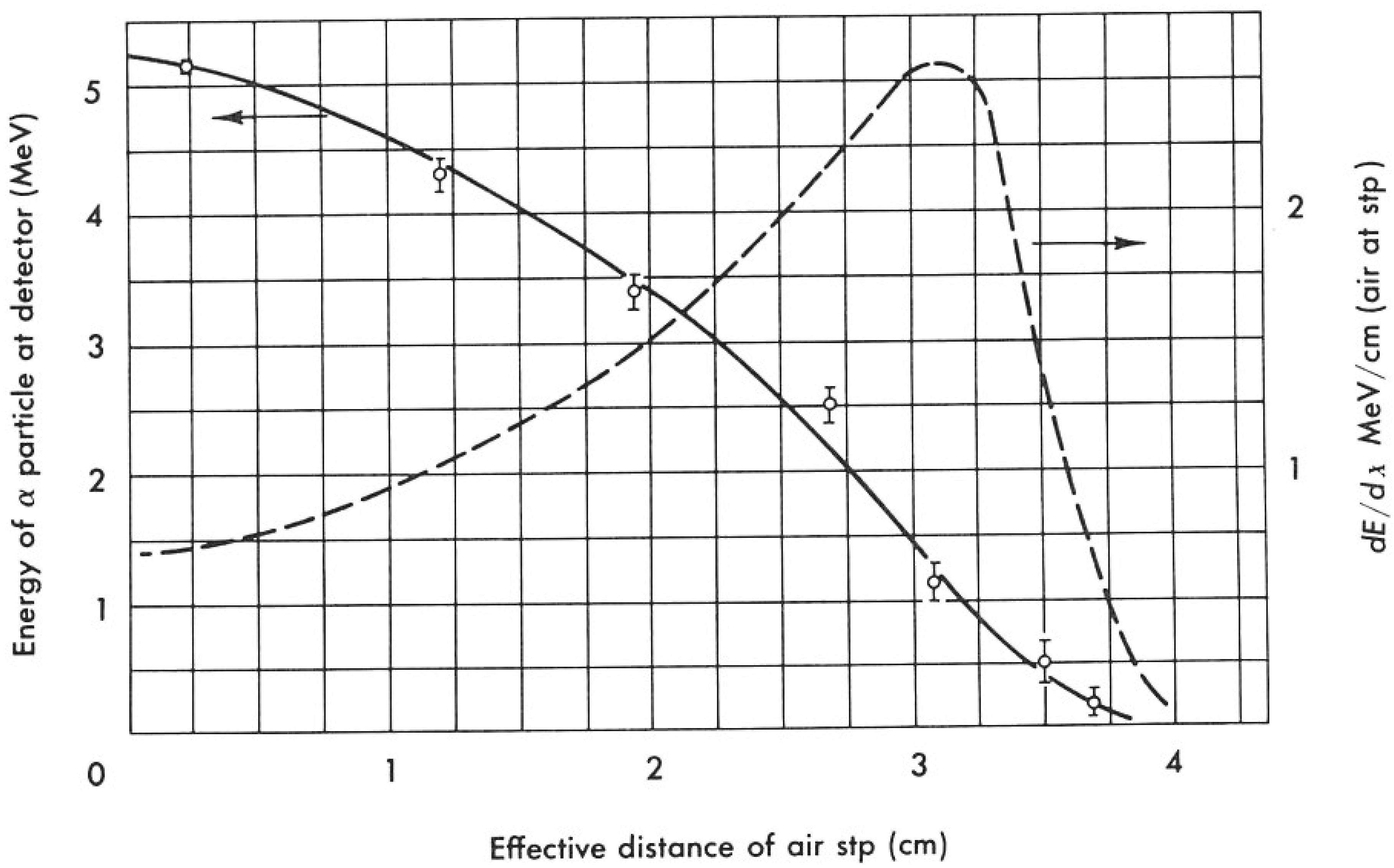


FIG. 5.42 Plot of the residual energy of a polonium alpha particle when it reaches the detector as a function of air pressure (plotted, however, in terms of the equivalent amount of air (stp) traversed). These data are obtained from distributions such as shown in Fig. 5.41. The dotted curve represents the derivative of the solid (energy) curve; thus it gives the energy loss per unit length. It is called the "Bragg curve."

the energy of the alphas as a function of material traversed. The results, obtained by a student† are given in Fig. 5.42 (solid curve).

If the derivative of the energy curve is taken with respect to distance, we obtain the energy-loss curve, dE/dx, as a function of distance, as shown by the dotted curve in Fig. 5.42. Such a curve is called a Bragg curve, and shows a $1/E$ dependence‡ as predicted by Eq. 2.10; for these very slow particles $E = \frac{1}{2}Mv^2$ and the influence of the logarithmic term of Eq. 2.10 is minimal. As the particle reaches the end of its range the energy loss dE/dx drops rapidly to zero.

From the energy curve of Fig. 5.42, we note that in air at stp the polonium alpha particle produces at the end of its range approximately 67,000 electron-ion pairs per centimeter, whereas at its full energy it produces only 20,000 pairs per centimeter; these numbers were obtained by using an average loss of 36 eV for the production of one electron-ion pair in air. More accurate results, especially close to the stopping point, can be best obtained with special ionization chambers.

† K. Douglass, class of 1964.

‡ We might plot the dE/dx curve against energy by making use of the data of the energy curve to express the distance from the stopping point in energy units.

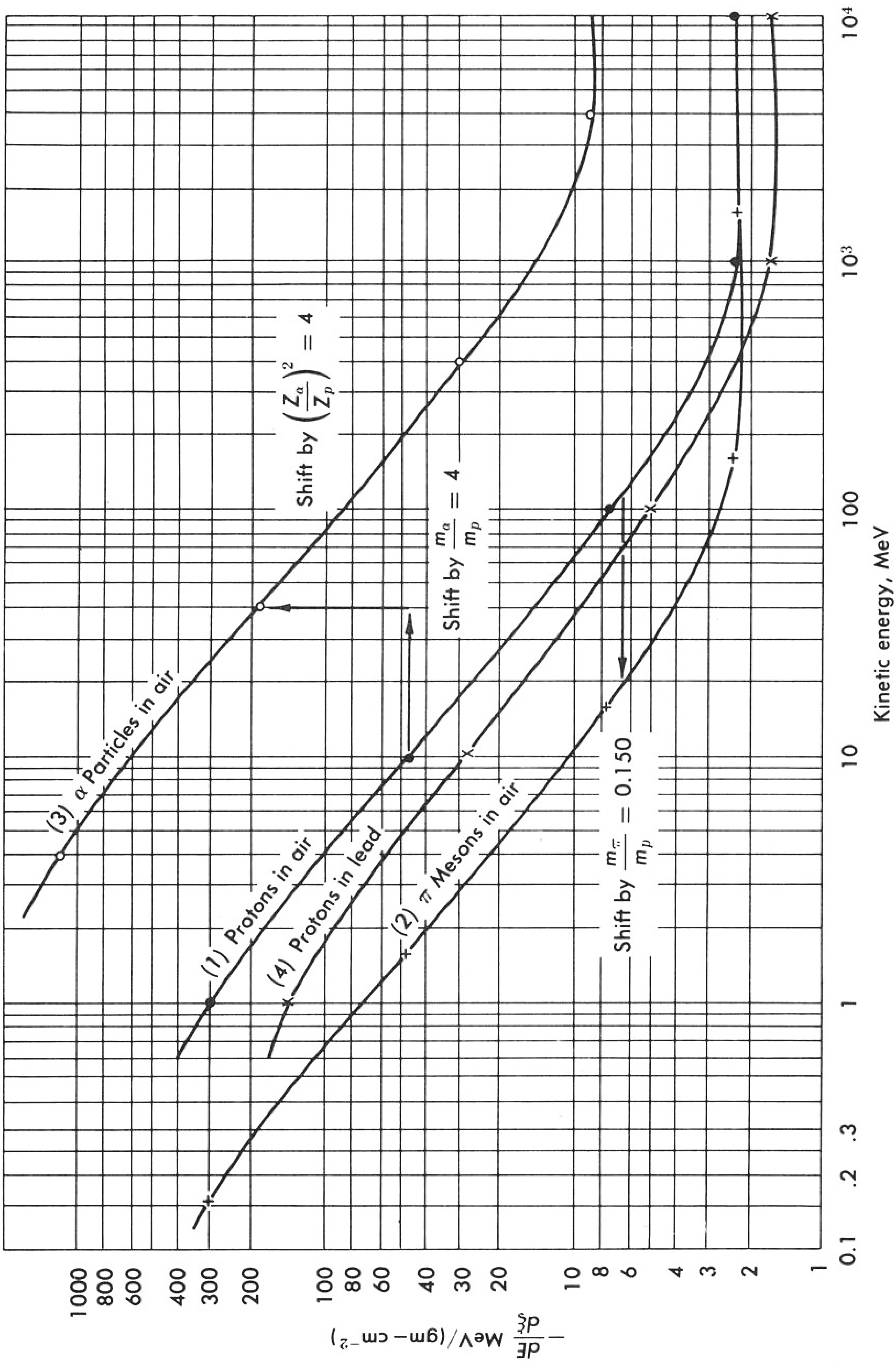


FIG. 5.4 Energy-loss curves for different charged particles in air and in lead. Note how all the curves are related to one another.

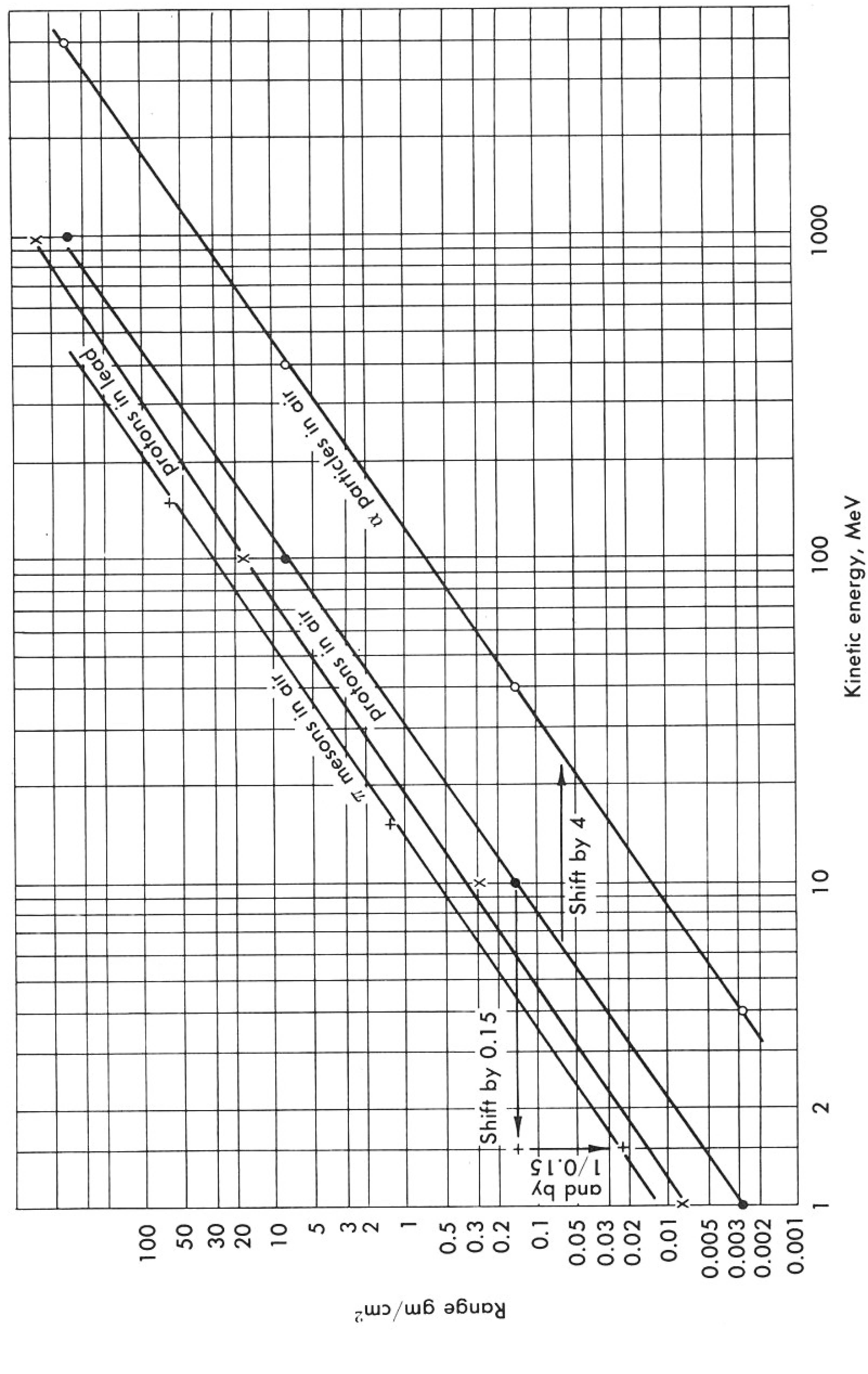
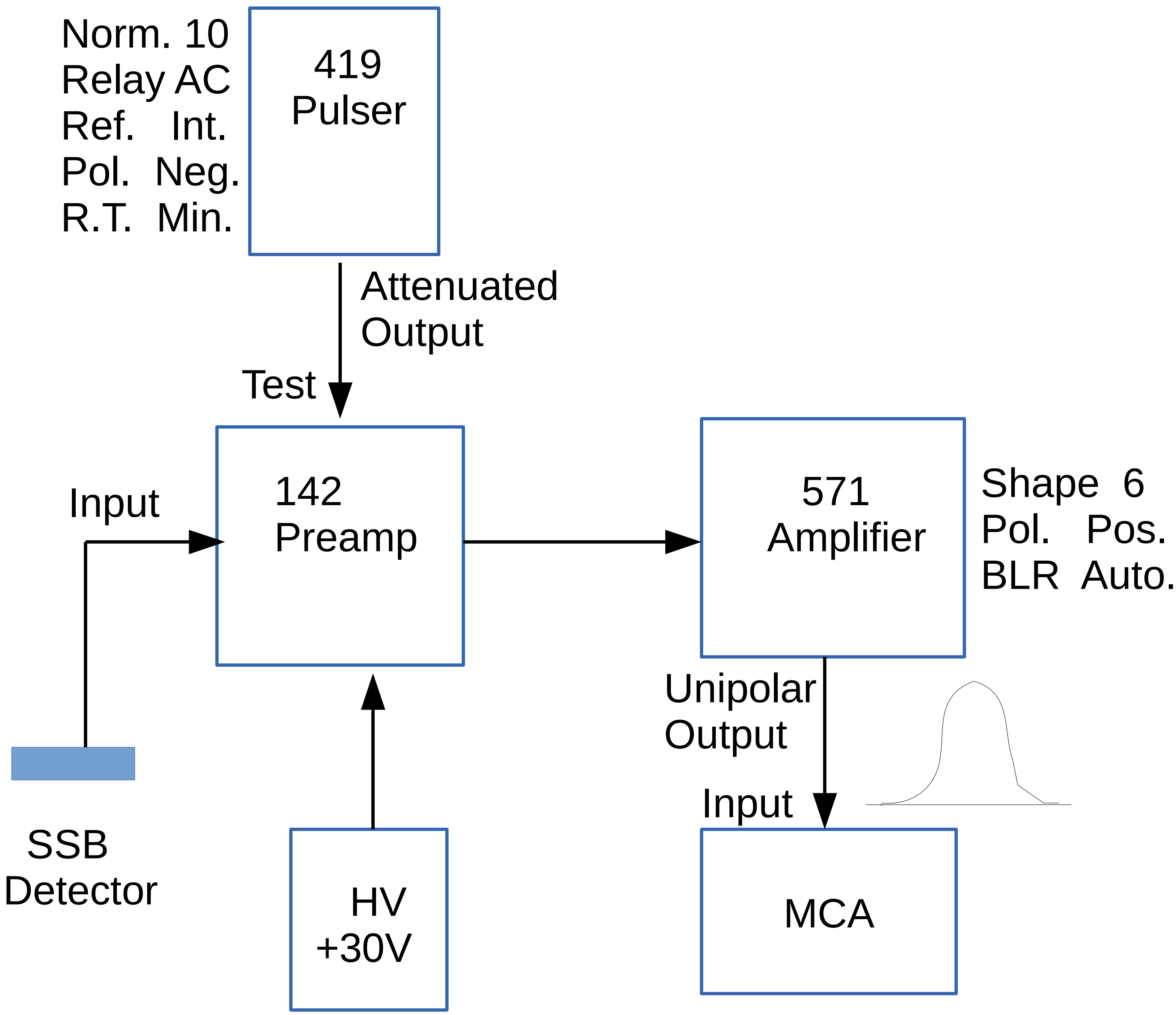


FIG. 5.5 Range curves for different particles in air and in lead. Note how the different curves are related to one another.

SSB Detector Electronics



Maestro Multi-Channel Analyzer (MCA)

Maestro is the data management program which collects digitized data from the multi-channel analyzer (MCA) and creates histograms which you can then analyze and store. The MCA accepts positive unipolar pulses with a maximum amplitude of 10 volts.

Simply click on the Maestro icon to start the program. The title bar on the display shows the source of the data presented in the histogram: MCB signifies that the data are live events collected from the multi-channel analyzer, and BUFFER indicates you are looking at previously saved data. You can open a new window containing MCB or BUFFER data by selecting from the DETECTOR LIST on the toolbar. The title bar of the active window is the one which is highlighted; the active data set is the one currently being controlled by the program commands. You can switch between active windows with the mouse or pointer.

Each window has two views of the spectrum: an EXPANDED view, and a FULL view. The FULL spectrum view is located in the inset, and is always given with a logarithmic vertical scale. The highlighted region within the FULL view shows the region of the spectrum which is presented in the EXPANDED view. A marker (vertical line) shown in the EXPANDED view can be set by positioning the mouse pointer at the desired channel and left-clicking the mouse. The numerical value of the marker position is shown beneath the display window.

A "Region of Interest" (ROI) can be set within a spectrum and used to extract a peak area. Pull down the ROI menu, select MARK, and use the → and ← keys to select the ROI. Once the channels are defined, de-select the MARK feature in the menu. To erase a ROI, you can use the UnMARK option in the ROI menu along with the right and left arrow keys, or select ROI/CLEAR from the menu. To calculate the sum of the counts in a ROI, select the CALCULATE/SUM option from the menu; the ROI sum appears beneath the spectrum.

The data acquisition is started and stopped with the ACQUISITION menu. This menu also contains the CLEAR option to erase the displayed MCB data. The FILE/OPEN menu allows you to retrieve previously saved data into a BUFFER histogram. Also, to move "live" data into a buffer, right-click on the mouse within an MCB histogram. Then, select the option to transfer the histogram to a displayed BUFFER.

Any histogram can be saved to disk with the FILE/SAVE-AS menu option. If you specify the IntegerCHN file option, then the saved file can be easily plotted on a Windows machine by right-click on the file name, then OPEN WITH, then select WinPlots. Alternately, you can save the spectrum using the ASCII file option. The yields in each spectrum channel are then easily accessed for plotting or further calculation by opening this file with the LibreOffice spreadsheet. You can then add a column to this data set specifying the channel number within the range from 0 to 511. Alternately, the data file can be read into a Python program, where plots and other calculations are easily made.

The MCA can be calibrated so as to provide the energy associated with each channel. However, *we strongly suggest that you record your data in units of "channels," and do not attempt to calibrate the MCA.* Simply ignore the "energy" values reported for the cursor/marker location, or turn off the MCA calibration using the menu items CALCULATE/CALIBRATE/DESTROY CALIBRATION. The location of the marker/cursor appears in units of channels at the bottom left corner of the screen.

If absolutely necessary, you can do a rough "on-line" energy calibration of your spectra using the CALCULATE/CALIBRATE menu option. With the marker positioned on a known peak, you will be prompted to enter the peak energy. Do this for all known calibration points. The marker position will subsequently read out in energy units. (If you enter only one calibration point, the program will assume that zero energy falls in channel zero.)

The manual can be consulted to learn about many other options.

ORTEC®

142PC
Preamplifier

- **Ideal for proportional counters**
- **High sensitivity and very low noise for soft x-ray and low-energy gamma spectroscopy**
- **Accepts 0 to ±3 kV bias**

The ORTEC Model 142PC Preamplifier is a low-noise charge-sensitive unit especially designed for use with proportional counters requiring up to ±3000 V detector bias.

The high sensitivity of this unit often allows operating the proportional counter at reduced voltages, thus greatly minimizing peak position shifts and peak broadening with changing count rates.

The low-noise performance for this type of preamplifier greatly improves the resolution of the spectroscopy system. The separate energy and timing outputs enhance instrument flexibility.

The Model 142PC incorporates a protection circuit for the input FET to prevent damage from inadvertently applied overvoltages. The unit is shipped with the protection circuit in place; better resolution, however, will be obtained when the protection is removed (Fig. 1).

Specifications

PERFORMANCE

Noise	Typical	Guaranteed
0 pF	295 rms electrons	<340 rms electrons
100 pF	450 rms electrons	<485 rms electrons

RISE TIME Based on a +0.5 V signal through either output into a 93-Ω circuit and measured from 10% to 90% of peak amplitude; 25 ns at 0 pF and 150 ns at 100 pF.

SENSITIVITY Nominal, measured through either output, 6.5 V/pC.

DYNAMIC INPUT CAPACITANCE 1000 pF.

INTEGRAL NONLINEARITY ≤±0.05% for 0 to ±7 V open circuit or ±3.5 V terminated in 93 Ω.

OUTPUT LINEAR RANGE ±7 V.

TEMPERATURE INSTABILITY ≤±50 ppm/°C, 0 to 50°C.

DETECTOR BIAS ISOLATION ±3000 V.

OPEN LOOP GAIN ≥40,000.

INPUTS

INPUT Accepts input signals from a proportional counter and extends operating bias to the proportional counter.

BIAS Accepts the bias voltage for the proportional counter from a bias supply.

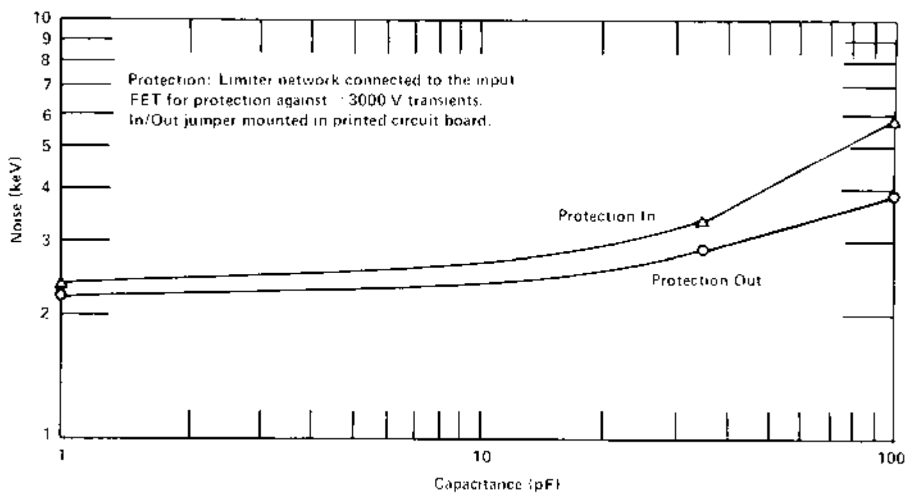


Fig. 1. Noise as a Function of Input Capacitance, Measured with an ORTEC Model 572 Amplifier and 2-μs Time Constant.

142PC
Preamplifier

TEST Accepts input voltage pulses from a pulse generator for instrument and system check and calibration; R_{in} = 93 Ω.

OUTPUTS

ENERGY AND TIMING 2 connectors furnish identical signals through 2 output paths; either or both of these outputs can be used as required, and they are interchangeable. R_o = 93 Ω through each connector, and the output polarity is opposite from the input pulse polarity (output pulse polarity is the same as bias polarity).

CONNECTORS

INPUT AND BIAS SHV.

TEST, ENERGY, AND TIMING BNC.

POWER CABLE 3-m (10-ft) captive power cable. ORTEC 121-C1; longer lengths available on special order.

ELECTRICAL AND MECHANICAL

POWER REQUIRED +24 V, 30 mA; –24 V, 10 mA; +12 V, 15 mA; –12 V, 15 mA. Furnished from NIM bin and power supply through any ORTEC main amplifier or from an ORTEC Model 4002P Portable Power Supply; built-in captive cable is compatible with either source.

WEIGHT
Net 0.65 kg (1.5 lb).
Shipping 1.3 kg (3.0 lb).

DIMENSIONS 4.5 X 13.2 X 10.0 cm (1.75 X 5.2 X 4.0 in.) plus 3-m (10-ft) cable.

Ordering Information

To order, specify:

Model	Description
142PC	Preamplifier

Suggested cable accessories:

C-24-12	RG-62A/U 93-Ω Cable with two BNC male plugs; 12-ft length
C-36-2	RG-59A/U 75-Ω Cable with two SHV female plugs; 2-ft length
C-36-12	RG-59A/U 75-Ω Cable with two SHV female plugs; 12-ft length

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ORTEC®

570
Amplfier

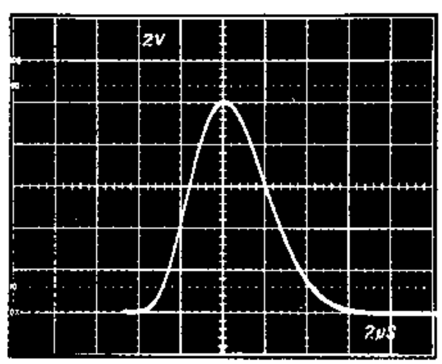
- **General-purpose amplifier for energy spectroscopy with all types of detectors**
- **Unipolar output**
- **Low noise, wide-gain range and front-panel selectable time constants**
- **Gated BLR with automatic threshold control for excellent counting rate performance**

The ORTEC Model 570 Amplifier is a general-purpose spectroscopy amplifier that offers excellent performance for varying counting rates at an economical price.

The low noise, wide-gain range and selectable shaping networks make this instrument ideally suited for operation with semiconductor detectors, proportional counters, and scintillation detectors in a wide variety of high-resolution spectroscopy applications.

The Model 570 incorporates an automatic gated baseline restorer, which causes the system resolution to be nearly independent of input counting rates. Figure 1 illustrates the peak shift and resolution for a typical γ-spec-troscopy system.

The gated baseline restorer (BLR) includes a discriminator that operates the sensing circuits that normally establish the baseline reference for the MCA.



2 V/cm, 2 µs/cm

UNIPOLAR OUTPUT

Performance of the spectrometer often depends on the precision of the setting of the BLR threshold. The Model 570 offers the convenience of an automatic threshold control, which typically gives as good or better results than those the most experienced operator could achieve manually.

The active filter networks of the Model 570 generate a very symmetrical unipolar output with optimal signal-to- noise ratio over a wide range of time constants.

The excellent dc stability of the Model 570 output eliminates spectrum broadening caused by dc drift and ensures that the high-resolution capability of germanium detectors is realized.

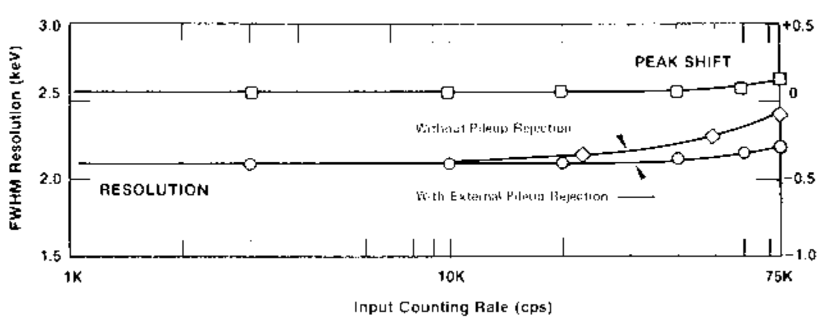


Fig. 1. Typical Resolution and Baseline Stability vs. Counting Rate for the Model 570 in a γ-Spectroscopy System.

570
Amplfier

Specifications

PERFORMANCE

GAIN RANGE Continuously adjustable from 1 to 1500.

PULSE SHAPE Semi-Gaussian on all ranges with peaking time equal to 2.2τ and pulse width at 0.1% level equal to 2.9 times the peaking time.

INTEGRAL NONLINEARITY For 2-μs shaping time, <±0.05%.

NOISE Typically <5 μV for unipolar output referred to the input, using 2-μs shaping and Coarse Gain ≥100.

TEMPERATURE INSTABILITY
Gain ≤±0.0075%/°C, 0 to 50°C.
DC Level ≤±50 μV/°C, 0 to 50°C.

BIPOLAR CROSSOVER WALK ≤±3 ns at 0.5 μs for 50:1 dynamic range, including contribution of an ORTEC Model 552 Single-Channel Analyzer.

OVERLOAD RECOVERY Recovers to within 2% of rated output from X300 overload in 2.5 nonoverloaded pulse widths using maximum gain for Unipolar Output.

SPECTRUM BROADENING Typically <16% FWHM for a ^{60}Co 1.33 MeV gamma line at 85% of full scale for an incoming count rate of 1 to 75,000 counts/s (Unipolar Output, 2-μs shaping).

SPECTRUM SHIFT Peak position shifts typically <0.024% for a ^{60}Co 1.33-MeV gamma line at 85% of full scale measured from 1 to 75,000 counts/s (Unipolar Output, 2-μs shaping).

CONTROLS

FINE GAIN 10-turn precision potentiometer with graduated dial for continuously variable direct-reading gain factor of X0.5 to X1.5.

COARSE GAIN 6-position switch selects feedback resistors for gain factors of 20, 50, 100, 200, 500, and 1k. Jumper on the printed wiring board (PWB) selects X0.1 attenuation.

INPUT POLARITY Locking toggle switch selects either Pos or Neg input pulse polarity.

SHAPING TIME 6-position switch selects time constants for active pulse-shaping filter network from 0.5, 1, 2, 3, 6, and 10 μs.

PZ ADJ Screwdriver adjustable potentiometer to set the pole-zero cancellation to compensate input decay times from 40 μs to ∞.

BLR 3-position locking toggle switch selects the source of control for the gated baseline restorer discriminator threshold from:
Auto The BLR threshold is automatically set to an optimum level, as a function of the signal noise, by an internal circuit.
PZ Adj The BLR threshold is determined by the threshold potentiometer. The BLR time constant is also greatly increased to facilitate PZ adjustment; this position may give the lowest noise for count rates under 5000 counts/s and/or longer shaping times.
Threshold The BLR threshold is manually set by the threshold potentiometer.

DC Screwdriver adjustable potentiometer to set the Unipolar Output dc level; range ±100 mV.

INPUT

INPUT Front-panel BNC connector accepts either positive or negative pulses with rise times of 10 to 650 ns and decay times of 40 μs to ∞, $Z_{in} \cong 1000\ \Omega$ dc-coupled; linear maximum 10 V; absolute maximum 20 V.

OUTPUTS

UNIPOLAR Front-panel BNC connector with Z_o <1 Ω, short-circuit proof; prompt with full-scale linear range of 0 to +10 V; active filter shaped; dc-restored; dc-level adjustable to ±100 mV.

PREAMP POWER Rear-panel standard ORTEC power connector. Amphenol 17-10090, mates with captive and noncaptive power cords on all ORTEC pre-amplifiers.

BUSY OUTPUT Rear-panel BNC connector with Z_o <10 Ω provides a +5 V logic pulse for the duration that the input pulse exceeds the baseline restorer discriminator.

ELECTRICAL AND MECHANICAL

POWER REQUIRED +12 V, 60 mA; –12 V, 30 mA; +24 V, 80 mA; –24 V, 85 mA.

WEIGHT
Net 1.5 kg (3.3 lb).
Shipping 3.1 kg (7.0 lb).

DIMENSIONS Standard single-width NIM module 3.43 X 22.13 cm (1.35 X 8.714 in.) per DOE/ER-0457T.

Ordering Information

To order, specify:

Model	Description
570	Amplifier

Specifications subject to change
022603

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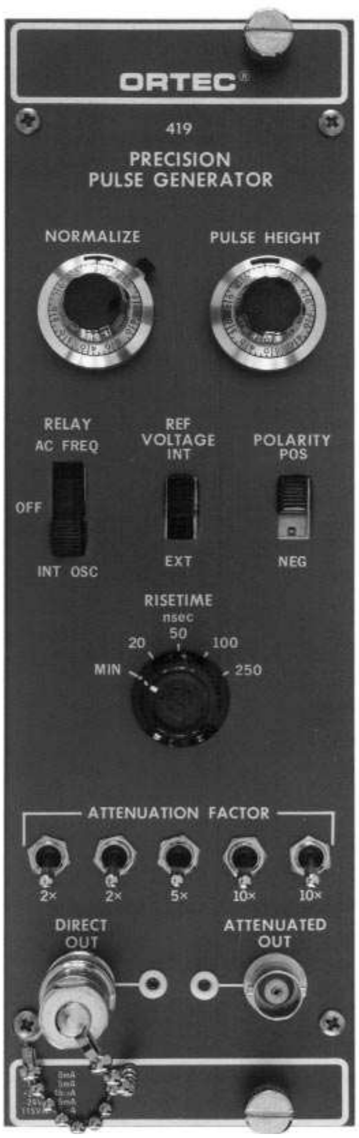
419

Precision Pulse Generator

- **Simulates detector output signals**
- **Precision dial may be calibrated to read directly in terms of equivalent energy deposition in semiconductor detectors**
- **Exponential pulse shape with 5- to 250-ns rise time and 200- or 400-μs decay time constant**
- **Line frequency or 70-Hz pulse rate**
- **Positive or negative polarity**
- **Direct 0 to 1-V output (0 to 10 V with external reference voltage)**
- **Attenuated output with 2000:1 attenuation range**
- **Internal or external reference voltage**



The ORTEC Model 419 is a Precision Pulse Generator that simulates the detection of a nuclear particle reaction in a semiconductor or scintillation detector, as well as serving as a specialized pulse generator for use with pulse processing instrumentation. It can be calibrated to read directly in terms of equivalent energy deposition in semiconductors, and the rise time of the pulse may be varied to simulate the collection time constant in the detector.

The pulses are generated with a mercury-wetted relay that can be operated asynchronously from the line frequency for measurement of spectral broadening caused by hum and ripple of the ac line.

A charge terminator and a 100-Ω voltage terminator are provided with this instrument. The use of the charge terminator allows the voltage pulse to be converted to a charge pulse for subsequent amplification by a charge-sensitive preamplifier. The use of the voltage terminator allows the voltage pulse to be input directly to other instruments such as amplifiers, discriminators, and ADCs. A holder is provided on the rear panel to store the charge terminator when it is not in use.

The Model 419 maintains the selected amplitude through long experiments because of excellent stability against changes in line voltage and ambient temperature.

Using the Internal Reference Voltage, the output peak amplitude can be adjusted from 0 to +1 V when both outputs are terminated with 100 Ω loads. The Attenuation Factor affects only the Attenuated Output, and permits reducing the amplitude for driving the input of a high-gain amplifier

An external reference voltage may be used, up to 20 V maximum, to generate arbitrary waveforms, such as a ramp input, to check overall system linearity. The output level is 50% of the input.

Specifications

PERFORMANCE

PULSE AMPLITUDE Output peak adjustable from 0 to ±1 V. This converts to 0–2 pC, using the charge terminator supplied, and is equivalent to 0–44 MeV referred to a silicon semiconductor detector. Rise time is selected by front-panel switch; fall time is an exponential decay time constant of 200 μs (terminated) or 400 μs (unterminated).

TEMPERATURE INSTABILITY <±0.005%/°C from 0 to 50°C.

LINE VOLTAGE INSTABILITY <±0.001% per 10% change in power line voltage.

RIPPLE AND NOISE ≤0.003% of pulse amplitude.

PULSE REPETITION RATE Either the ac power line frequency, or 70 ±10 Hz using the internal oscillator.

INTERNAL OSCILLATOR
Temperature Instability <±0.05%/°C, 0 to 50°C.
Time Instability <±1%/day.

CONTROLS

PULSE HEIGHT 10-turn potentiometer with a duo-dial adjusts the output pulse amplitudes at both outputs within a total range; the range is a combined function of the reference and the setting of the Normalize control. Linearity ±0.1% of full scale.

NORMALIZE 10-turn potentiometer adjusts the total range for the Pulse Height control when using Ref Voltage Int switch; full-scale range from ±0.5 V to ±1 V; linearity, ±0.1% of full scale.

RELAY 3-position slide switch selects the ac power line frequency or the internal 70-Hz oscillator for the output repetition rate, and includes an Off position to set the pulser at standby.

REF VOLTAGE 2-position slide switch selects either the internal reference voltage for a 100% normalized full-scale range of 0 to ±1 V or the external reference voltage for an output full-scale range and polarity that are determined by the level furnished through the rear-panel BNC connector.

POLARITY 2-position slide switch selects either polarity for the output pulses when using the internal reference.

RISE TIME (nsec) 5-position rotary switch selects the rise-time shaping for the output pulses to simulate various types of detectors; selections are MIN (~5 ns), 20, 50, 100, and 250 ns.

419
Precision Pulse Generator

ATTENUATION FACTOR 5 toggle switches select a step attenuation for output pulses furnished through the Attenuated Output connector; the factors are 2, 2, 5, 10, and 10. They may be used in any combination to cover a 2000:1 dynamic range using 0.1% tolerance resistors.

INPUT

EXT REF Rear-panel BNC connector accepts an external reference voltage to control the full-scale Pulse Height control range and polarity when the front-panel Ref Voltage switch is set at Ext; maximum, ±20 V; output full-scale range, 50% of reference level with output terminated in 100 Ω.

OUTPUTS

DIRECT Front-panel BNC connector with an adjacent test point furnishes the adjusted and normalized full amplitude output pulses through an output impedance of 100 Ω.

ATTENUATED Front-panel BNC connector with an adjacent test point furnishes the same output pulses as above, with amplitudes attenuated by the factor selected with the 5 toggle switches.

PULSE HEIGHT VOLTAGE Two test points on the rear panel permit a dc voltmeter or oscilloscope to monitor the voltage level that is applied to the pulse-forming relay.

ELECTRICAL AND MECHANICAL

POWER REQUIRED +24 V, 45 mA; –24 V, 25 mA; +12 V, 0 mA; –12 V, 5 mA; 117 V ac, 10 mA.

WEIGHT
Net 2.0 kg (4.5 lb).
Shipping 2.9 kg (6.5 lb).

DIMENSIONS Standard double-width NIM module 6.90 X 22.13 cm (2.70 X 8.714 in.) per DOE/ER-0457T.

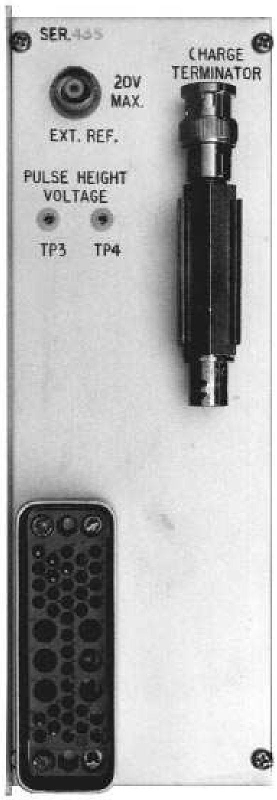
Included Accessories

VOLTAGE TERMINATOR A standard 100-Ω resistive terminator is attached to the Direct Output connector on the front panel to terminate the output correctly when only the Attenuated Output is being used.

CHARGE TERMINATOR A specially constructed terminator is mounted in a rear- panel clip and should be used to properly terminate the pulser output and feed a charge signal into the signal input of a charge-sensitive preamplifier when the output pulses are being furnished for this type of test.

Ordering Information

Model	Description
419	Precision Pulse Generator



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