10

Counting Systems

EXPERIMENT 10.1

Determination of the Voltage Characteristics of a Geiger Counter

APPARATUS

(a) End window Geiger counters (preferably low voltage *and* high voltage counters)
(b) Lead castle
(c) Scaler
(d) E.H.T. unit
(e) Probe unit
(f) β-radioactive source

THEORY

If a Geiger counter is operated at a fixed distance from a standard radioactive source, then the count rate is found to be dependent on the E.H.T. voltage applied to the tube and varies as shown in Fig. 10.1. Until the voltage reaches the starting potential the pulses from the counter are too small to be detected. However, as the voltage increases, the pulses are recorded in increasing numbers until the threshold is reached when the count rate becomes constant. The range of applied voltage over which this occurs is known as the Geiger plateau. Beyond the plateau, continuous discharge takes place and counting is not possible. The voltages of the threshold potential and of the plateau depend on the counter design and on the filling gas. By operating the counter at the centre of the plateau

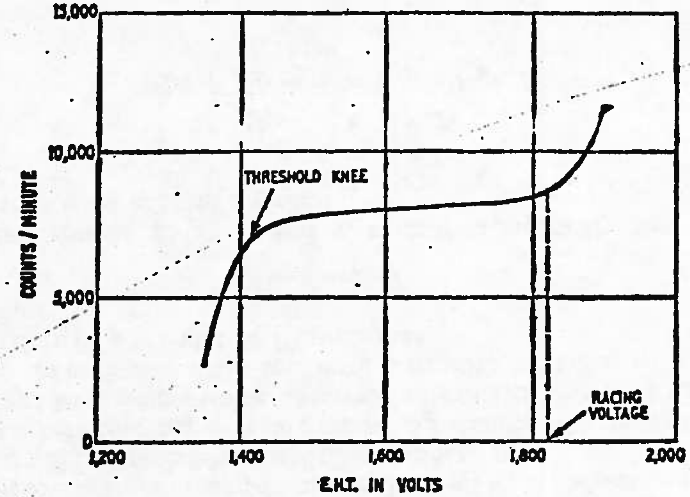

Fig. 10.1. Count rate versus E.H.T.

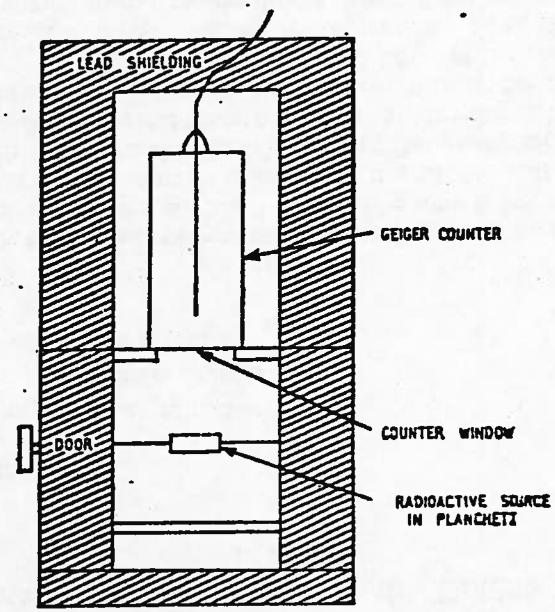

Fig. 10.2. Arrangement of counter

the count rate will be almost independent of the applied E.H.T., thus minimising the effect of small drifts in the E.H.T. Normally the plateau should be at least 200 V in length and should have a 'slope' not greater than 0·05% per volt for reliability and accuracy of operation. As a counter ages, the plateau decreases in length and increases in slope while the starting voltage increases and racing voltage decreases.

PROCEDURE

Arrange the Geiger counter and source in a lead castle as shown in Fig. 10.2. Connect the Geiger counter to the E.H.T. unit and a suitable scaler. Turn the E.H.T. controls to minimum and then switch on the apparatus allowing 30 min warming up time. Increase the E.H.T. volts slowly and note the voltage at which counting starts. Count for a suitable time interval (to give approximately 10,000 counts), at various E.H.T. voltages up to 250 V above the starting voltage, unless 'racing' starts, in which case reduce the E.H.T. voltage immediately. Plot the graph of count rate against E.H.T. voltage and determine the 'slope' of the plateau.

$$\text{Slope} = \frac{\text{change in count rate per V change in E.H.T.}}{\text{mean count rate}} \times 100\% \text{ per V}$$

$$= \frac{\text{slope of graph}}{\text{mean count rate}} \times 100\% \text{ per V}$$

For future operation of the counter select an E.H.T. voltage near the centre of the plateau obtained. In this experiment determine the characteristics of both high- and low-voltage counters if available.

Note—Geiger counters exhibit a peculiarity resembling hysteresis and consequently it is unwise to go back to check a point on the curve at lower voltage during the plateau determinations. If points do not fall on a smooth line, increase the voltage as far as required, then reduce the voltage to zero and wait a few minutes before increasing again to the desired value.

EXPERIMENT 10.2

Determination of the Dead Time of the Counter–Amplifier System by the Double Source Method

APPARATUS

(*a*) Geiger counting equipment
(*b*) Two β-radioactive sources
(*c*) Double-source holder

THEORY

After the electrons have been collected on the central wire electrode in the Geiger counter, a sheath of positive ions is left round the wire. This sheath increases in radius as it drifts towards the outer cylinder distorting the electric field and in effect producing a smaller potential gradient near to the wire so that until the sheath has grown to some radius depending on the applied voltage, the counter is insensitive. This time is called the 'dead time' of the counter and is of the order of a few hundred microseconds. Thus, if particles enter the counter during the dead time they will not be detected and since the number of particles entering the counter is a function of their rate of emission, it is essential to determine the dead time if one wishes to compare a strong source with a weak source. The strong source loses many particles in the dead time while the weak source will lose probably a negligible number.

Let a beta source give N counts/sec in a counter with zero dead time and let n counts/sec be observed in a counter with dead time T sec. In each second the counter is insensitive for a time nT and it therefore fails to count NnT counts/sec.
Therefore

$$N - n = NnT$$

For two sources giving n_1 and n_2 counts/sec separately and n_3 counts/sec when counted together:

$$N_1 - n_1 = N_1 n_1 T$$
$$N_2 - n_2 = N_2 n_2 T$$
$$(N_1 + N_2) - n_3 = (N_1 + N_2) n_3 T$$

These equations can be solved to give approximately

$$T = \frac{n_1 + n_2 - n_3}{2n_1n_2}$$

Here, terms of the order $(n\,T)^2$ have been neglected and it is assumed that the counts are equally spaced in time.

PROCEDURE

Set up the Geiger counting equipment as in Experiment 10.1 and record the background count rate. Introduce a β source (Sr^{90} foil is quite suitable) in the double source holder into the lead castle and record the count rate with this source. Place the second β source in the double source holder beside the first source and count the activity of the two sources together. Finally remove the first source and count the activity of the second source alone. Repeat this sequence of counting, average the counts and determine the dead time from the equation derived above. The determination of the background count rate is very important in this experiment since small errors in n_1, n_2 and n_3 may lead to very large errors in T.

Observation of the Random Nature of Radioactive Decay

APPARATUS

(*a*) Geiger counting equipment

(*b*) β-radioactive source

THEORY

Due to the random nature of radioactive disintegration, there is no 'true' count rate and it is only possible to refer to a 'mean' count rate. As the number of counts recorded increases it approaches more closely this mean value. The application of the laws of probability to radioactive disintegration was discussed in Chapter 1 where it was shown that the count rates follow a law known as the Poisson distribution. An approximate form of the Poisson distribution known as the Gaussian distribution is normally used for statistical calculations and this is shown in Fig. 10.3. The width of the curve is expressed by the variance, v, where the variance is the average of the squares of the deviations from the mean count and can be shown to be equal to the mean count, m. The square root of the variance is known as the standard deviation σ, which is thus equal to the square root of the mean count.

The probability $P_0(t)\mathrm{d}t$ of the relative error

$$t = \frac{n - m}{\sigma}$$

where n = observed count, lying between t and $t + \mathrm{d}t$ can be shown to be

$$P_0(t)\mathrm{d}t = (2\pi)^{-1/2}e^{-t^2/2}\,\mathrm{d}t$$

If a large number of measurements is made, then the fraction having a deviation less than the standard deviation is equal to the area under the curve in Fig. 10.3 between the ordinates $t = -1$ and $+1$. Since this area is 68·3% of the total area under the curve, 32·7% of observations have deviations greater than the standard deviation and similarly 4·5% of the observations have deviations greater than twice the standard deviation. If a source is counted only once, the mean count is not known and thus there is a 68·3% chance that a single measurement will differ from the mean count

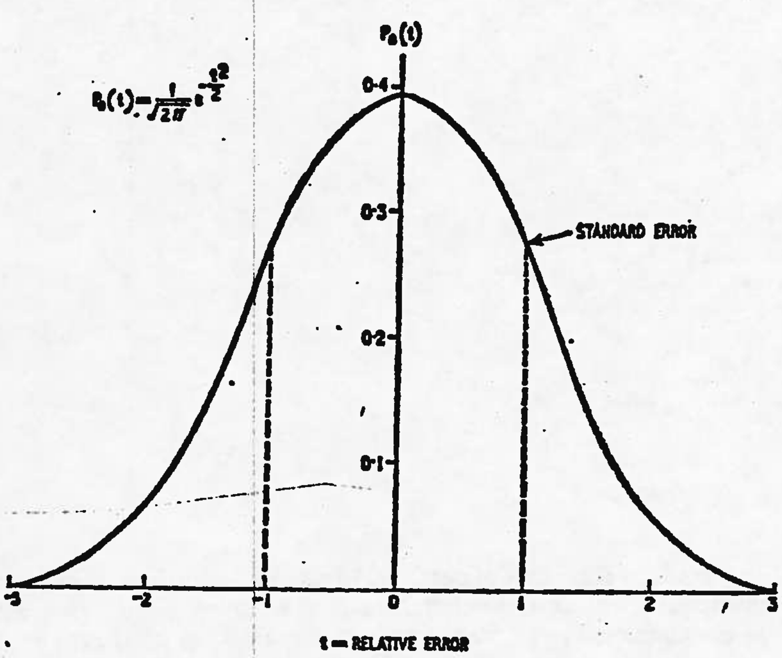

Fig. 10.3. Gaussian curve

by less than σ and a 4·5% chance that it will differ from the mean count by more than 2σ. Since $\sqrt{n}$ is usually small compared with n, little error is involved in assuming $\sigma = \sqrt{n}$ and hence the 'true' count is $n \pm \sqrt{n}$ with about one chance in three that these limits of error will be exceeded. To reduce the random error to 1%, it is necessary to record 10,000 counts and there is still about one chance in three of exceeding this error.

PROCEDURE

Set up the Geiger counting equipment in the usual manner. Place a standard source on a shelf of the lead castle at a distance such that the count rate is about 10,000 in a two minute period.

Take a series of two minute counts and record the observations. (At least 50 counts should be taken). From the measurements calculate:

1. The mean observed count rate.
2. The standard deviation of the observations.
3. The mean deviations of the observations.

From these values test the truth of the following statements:

1. The standard deviation = $\sqrt{\text{mean count}}$.
2. The mean deviation from the mean = $\frac{4}{5}$ of the standard deviation.
3. About $\frac{1}{3}$ of the deviations exceed the standard deviation.
4. About $\frac{1}{20}$ of the deviations exceed twice the standard deviation.

It may be found that the spread of the results is greater than predicted and this may be due to drift in the counting equipment or some other non-random variation. Alternatively the spread of the results may be less than predicted and this may be due to an effect tending to reduce the random nature of the readings such as a long paralysis time.

EXPERIMENT 10.4

Absorption and Range of Beta Particles of Phosphorus 32 in Aluminium

APPARATUS

(*a*) Geiger counting equipment
(*b*) Graduated aluminium absorbers
(*c*) P^{32} β-radioactive source
(*d*) Standard range-energy curve for beta particles in aluminium

THEORY

The absorption of beta particles in matter is, to a first approximation, independent of atomic number of the absorber, provided the thickness of the absorber is expressed in units such as mg/cm². For instance, 0·5 mm of lead absorbs beta particles to approximately the same extent as 2 mm of aluminium, since they both have a thickness of 570 mg/cm². It is therefore convenient to use aluminium absorbers so that the thinner absorbers are as accurate as possible.

The beta particles from P^{32}, a pure beta emitter, are absorbed by aluminium in the manner shown in Fig. 10.4. The 'tail' of the curve is due to γ radiation (bremsstrahlung), produced by the beta particles in the absorber. This tail is linear and hence can be extrapolated backwards so that a correction can be applied to the observed count rates for the γ-ray count. The curve due to the beta particles intersects the extrapolated bremsstrahlung curve and a visual determination of the range and thus the maximum energy of the beta particles is therefore possible by deciding where the intersection occurs.

PROCEDURE

The source used in this experiment is P^{32} and it is necessary to prepare this source from a solution of P^{32} supplied by R.C.C. Amersham. Pipette 0·1 ml of a 2·5 μc/ml solution of P^{32} on to a counting tray and then slowly dry the source under a heat lamp and seal when dry with Scotch tape. It is desirable also to have a stronger source for some observations and if available, prepare a second source in a similar manner from a 0·1 mc/ml solution of P^{32}.

Set up the Geiger counter apparatus and determine the working E.H.T. voltage. Count the background for several minutes. Place the weaker source on a shelf in the lead castle and count the activity for a sufficiently long time interval to give about 10,000 counts. Place aluminium absorbers of gradually increasing thickness between the source and counter and count the activity at each stage. The range of P^{32} beta particles in aluminium is roughly 800 mg/cm²

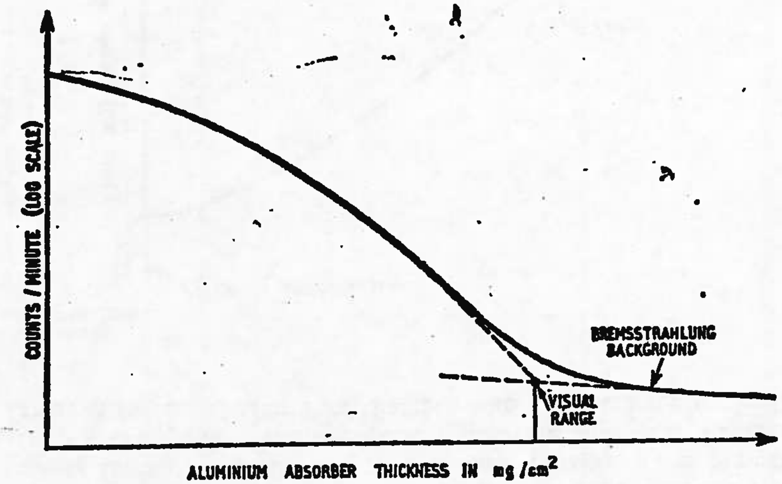

Fig. 10.4. Log count rate versus absorber thickness

and it is therefore not necessary to work through all the thinner absorbers, but a sufficient number of thicker absorbers must be used to enable the range to be determined accurately. When the count rate has fallen to about 300 counts/min, replace the source by the stronger one and repeat the counts with the last three absorbers used. These counts (corrected for dead time) should be 40 times greater than the corresponding counts with the weaker source. If the ratio is not 40, use the average value of the three ratios to correct all the remaining counts with the stronger source. Continue counting with increasing absorber thickness until several slowly decreasing points on the bremsstrahlung background have been obtained. To prevent hysteresis errors the counter must not be exposed to the sources when changing absorbers and accordingly it is necessary either to remove the source before the absorber is changed or to introduce a third absorber before the change over.

Correct the observed count rates for background counts and lost counts and after tabulating the corrected observations plot a graph on semi-logarithmic paper, of the corrected count rates against aluminium thickness. The aluminium absorber zero thickness is not the true zero since:

1. There is a Scotch tape covering ~10 mg/cm².
2. There is an air space between the source and counter, of thickness 1·3 mg/cm² for each centimetre of air path.
3. The thickness of counter window, normally marked on the counter, has been neglected.

In the experiment described above these absorbers are not very important for the high energy beta particles of P^{32} but they are important when low energy beta particles such as those from S^{35} or C^{14} are used.

The curve obtained should be of the form shown in Fig. 10.4 and by extrapolation of the bremsstrahlung curve the intersection of this curve and the absorption curve may be estimated. Determine the visual range and from the range–energy curve provided determine the corresponding maximum beta energy.

EXPERIMENT 10.5

The Feather Analyser

APPARATUS

(*a*) Geiger counting equipment
(*b*) Graduated aluminium absorbers
(*c*) P^{32} β-radioactive source
(*d*) Beta–gamma emitting radioactive source
(*e*) Standard range-energy curve for beta particles in aluminium
(*f*) Drawing materials

THEORY

The visual method of deciding where the absorption curve intersects the extrapolated bremsstrahlung curve in Experiment 10.4 is rather inaccurate particularly if a gamma background is present from a beta–gamma emitter. Under these circumstances, Feather analysis (so called after Prof. Feather who suggested the method)

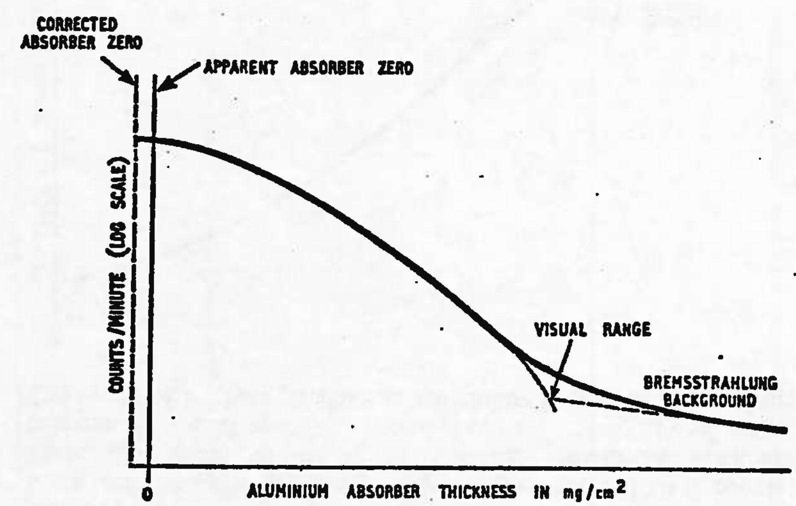

Fig. 10.5. Log count rate versus absorber thickness

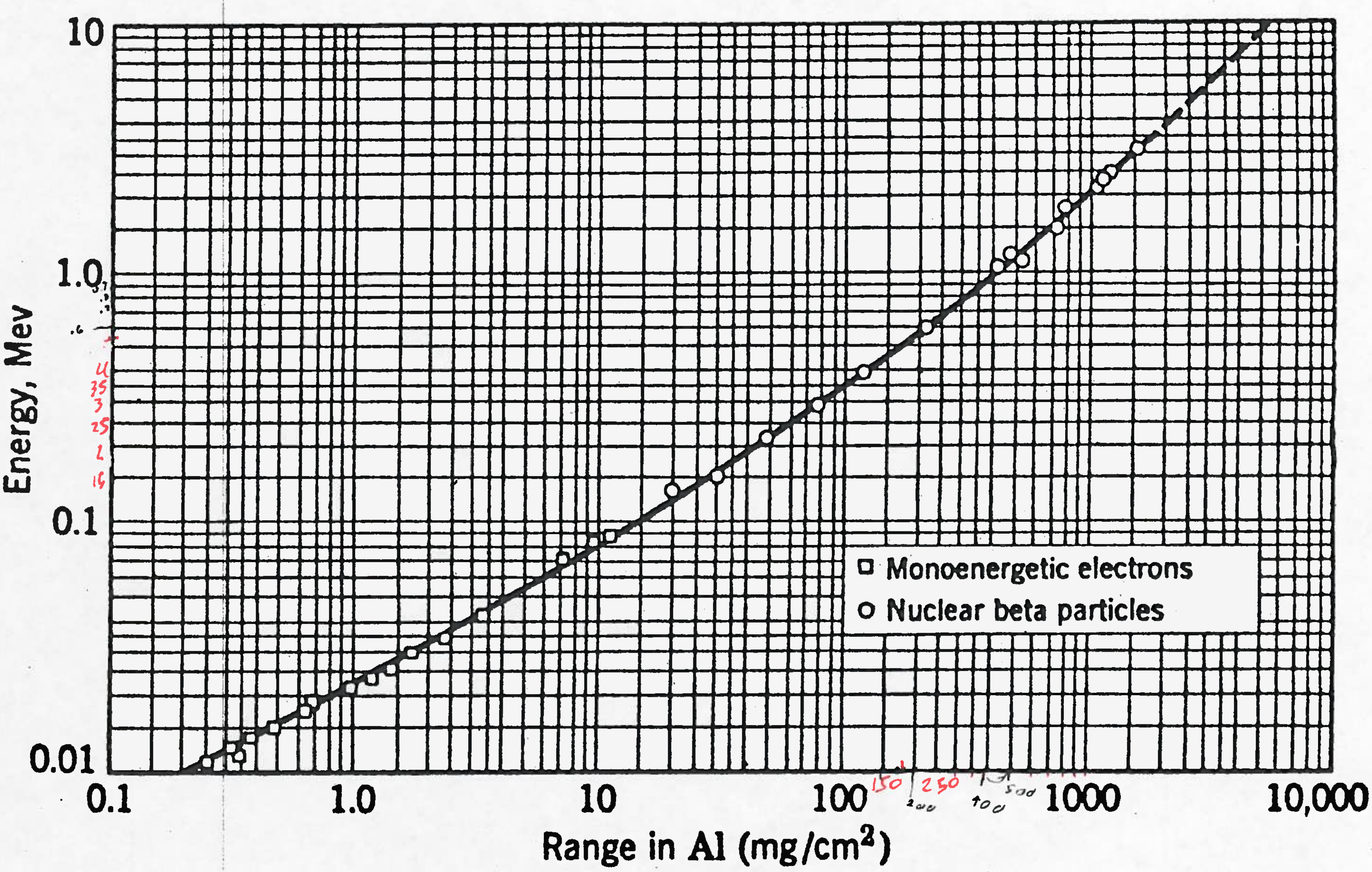

FIG. 8. End points in aluminum for nuclear beta rays of various maximum energies and for monoenergetic electrons of various energies. From Glendenin (Gl48).