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Publication Date
1952-11-24

UNIVERSITY OF CALIFORNIA – BERKELEY

RADIATION LABORATORY

UNCLASSIFIED

UCRL-2031
Unclassified-Physics Distribution

UNIVERSITY OF CALIFORNIA
Radiation Laboratory

Contract No. W-7405-eng-48

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November 24, 1952

Berkeley, California

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Useful methods of identifying particles of different mass often involve a measurement of specific ionization and some other parameter such as momentum, energy, or range. These schemes require a counter of small stopping power and good proportionality to measure the ionization. It has often been thought that a gas proportional counter admirably satisfies these requirements, on the assumption that the statistical fluctuations in the energy loss of the particles traversing the counter are governed by the statistical fluctuations in the number of ion pairs, as calculated on the basis of about 25 ev per ion pair. Experiment and the theory of Landau and of Symon indicate, however, that the fluctuations are considerably larger.[1, 2, 3.]

Protons of 31.5 Mev energy from the Berkeley linear accelerator were scattered elastically from a 0.00025-inch Pb target through a proportional counter and stopped in a NaI counter. The solid angle accepted was defined by a 1/8-inch hole in a brass plate 10-inches from the target; this hole was centered on the 0.0005-inch thick, 1/4-inch diameter windows of the proportional counter. The counter telescope and target were in an evacuated scattering chamber. The scattered protons passed through the cylindrical counter perpendicular to its axis and straddling the wire. The counter was 3/4-inch I.D. and 5-inches long. The 0.003-inch stainless steel wire was accurately centered; the counter was thoroughly outgassed and filled with a mixture of 96 percent A and 4 percent CO_2 and operated at 1700 volts. The elastic protons were separated by means of a single channel pulse height analyzer fed from the NaI counter, and the output of the analyzer was used to trigger the sweep of an oscilloscope; the proportional counter pulses after amplification and suitable delay were applied to the vertical plates. The oscilloscope screen was photographed on moving film and the film read on a microfilm viewer. The stability and linearity of the system has been shown to be reliably good in previous work.

An estimate of the inherent resolving power of the proportional counter was obtained by a pulse height analysis of the pulses from collimated 5.5 Mev alpha particles, which had an energy of 1.6 Mev and a range of about 3/4 cm after penetrating the counter window. The observed distribution was approximately Gaussian with a full width at half maximum of 17 percent. Lack of perfect collimation would introduce about 3 percent spread. The effect of fluctuations in energy loss in passing through the window are difficult to estimate; range straggling at this energy is about 2.5 percent and, as the counter sees only the end of the track, this fluctuation is magnified by a factor of four or more. Thus the inherent resolving power of the proportional counter is 12 percent or better and certainly adequate to investigate the observed distribution.

Figure 1 shows the histogram of 1636 pulses read. Amplifier noise limited the accuracy of reading the pulses to within the channel widths chosen. The pulse height distribution has been observed to be independent of beam intensity, thus indicating that no significant part of it is due to pileup. A theoretical curve was computed from the formulas and curves of Symon.[2] For comparison with experiment, both the theoretical curve and the experimental points were plotted on log-log graphs; the best fit by eye then gave scaling factors for both coordinates. The solid curve is the resulting theoretical distribution; no additional factors introducing spread have been folded in. The theoretical values of average total energy loss and of maximum energy loss by a 31.5 Mev proton in a single collision with an electron are shown. For comparision there is also shown a Gaussian distribution about the average of the width determined by statistics on the number of ion pairs formed at 25 ev per ion pair. The Gaussian curve is arbitrarily normalized to the same maximum value as the Landau distribution.

The surprisingly broad distribution with a high energy tail is due to the non-negligible probability of collisions in which the charged particle imparts large kinetic energy to the electron. This reduces radically the number of primary collisions, thus increasing the width of the statistical distribution and in addition gives rise to the high energy tail. Note in Figure 1 the maximum allowable energy loss in a single collision is, in this particular case, approximately twice the average total energy loss of the proton in the counter. This is in sharp contrast to the very narrow pulse height distributions that have been observed in the case in which the charged particle expends its entire track in the counter because, in this case, the statistical fluctuations are due only to the variations in the ratio of energy loss in ionization to energy loss in excitation.

The authors express their appreciation for advice given by Professors L. Alvarez and O. Chamberlain. This work was performed under auspices of the AEC.

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2. K. R. Symon, thesis (unpublished) Harvard University, 1948. Parts of this work appear in Rossi, High Energy Particles, Prentice-Hall, 1952.
3. N. Bohr also discusses the theory in Phil. Mag. 30, 581 (1915) and Kgl. Danske Videnskab. Selskab Mat. -fys Medd. 18, No. 8. The Landau effect has also been observed with minimum ionization electrons and mesons. See for example Hanson, Goldwasser, and Mills, Phys. Rev. 86, 617A (1952) and Hudson and Hofstadter, Phys. Rev. 88, 589 (1952).

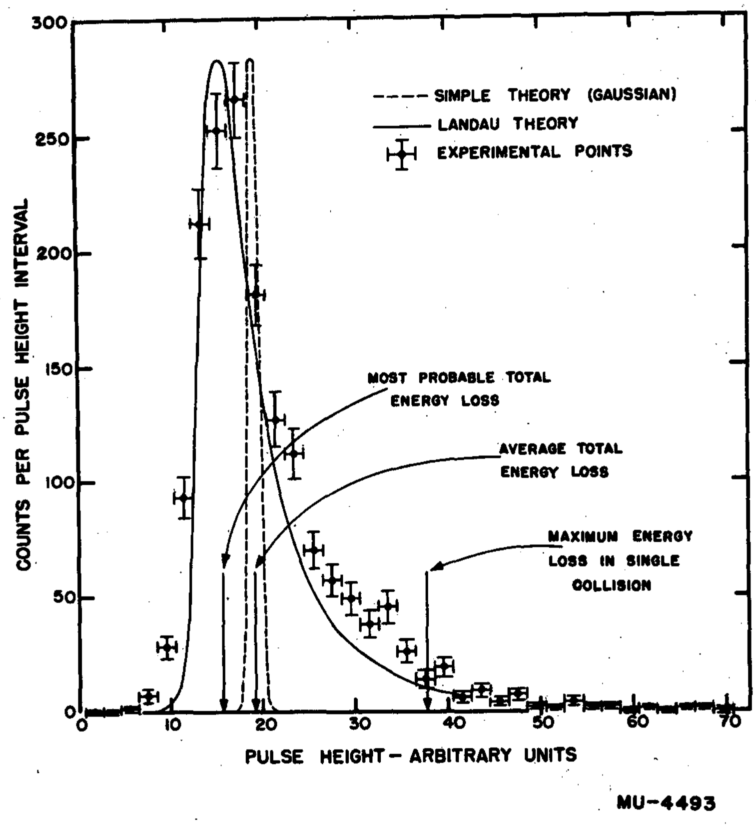

Fig. 1

Frequency distribution of energy losses of 31.5 Mev protons traversing 3/4" proportional counter. Histogram of experimental points shows standard deviations and channel widths. The theoretical Landau distribution is computed from Symon.[2] The dashed curve is a Gaussian distribution based on ion pair statistics. See text for fuller explanation.