The Absorption of High Energy Electrons. Part III

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Losses in lead of electrons with energies both above and below the range previously used (2 to 11 Mev) have been measured. For the low energy group electrons from radioactive P^{32} were sent through lead laminae of two thicknesses placed in the center of a cloud chamber. In this energy region the losses in lead should be due almost entirely to ionization processes. The experimental values for the energy losses are from 2 to 4 times those given by the Bloch formula. For the high energy group the electrons and positrons produced by the $Li+H^1$ gamma-radiation were used. The values found are about 50 percent greater than the calculated losses due to ionization and radiation, but are in good accord with the previous experimental values.

INTRODUCTION

THE first two papers of this series[1,2] dealt with the loss in energy which electrons with kinetic energies ranging from 2 to 11 Mev undergo in traversing carbon and lead absorbers. The apparently anomalous behavior of electrons at somewhat lower energies noticed by various experimenters[3,4] led to the present extension which includes the energy losses in lead experienced by electrons with an energy of about 1 Mev. Because of the importance, especially for cosmic-ray data, of a comparison between the energy losses of electrons and those of positrons we have also measured the losses in lead of positrons having initial kinetic energies between 5 and 15 Mev. We have considered separately the cases in which particles are scattered through an angle of more than 90 degrees and thus are reflected from the absorber. It is probable that such information will be important to any theory which deals with the effect of scattering on the observed energy loss.

EXPERIMENTAL TECHNIQUE

Low energy group

The beta-rays emitted by phosphorus bombarded by deuterons in the Michigan cyclotron provided a convenient source of electrons, because of the long (fourteen day) half-life. This P^{32} source was placed about 15 cm away from a small Cellophane window, 0.1 mm thick, in the wall of the cloud chamber.[5] As a rough selector lead blocks were placed between the source and the window in the magnetic field around the chamber. These blocks were arranged so that electrons of various energies, ranging from 0.35 to 1.35 Mev, were allowed to enter the chamber. The magnetic field employed was 460 oersteds, kept constant to within 5 percent.

Since air at 0.8 atmospheres pressure was used in the cloud chamber throughout the experiment, it was necessary in the case of the lowest energy group (0.5 Mev) to discard a considerable number of tracks which were visibly scattered in the gas. For this reason we cannot place as much faith in the results for the 0.5 Mev group as for those of higher energy. Two different lead laminae were used as absorbers, placed across the center of the chamber. Their thicknesses, as determined by weighing, were 0.0038 and 0.0066 cm.

The energy losses were determined by measuring the momenta of the electrons in terms of their radii of curvature on both sides of the absorber. To aid in achieving an impersonal selection of the tracks, that side of the chamber on which the particles emerged was hidden from view during the measuring of the incident energy. Stereoscopic pictures were taken in the experiments on the low energy electrons by use of an arrangement with a single mirror in which both the direct and the indirect views were photographed side by side on the same film. This reduced the possibility of counting as one track what might in reality be two parts of two different tracks.

[1,2] Turin and Crane, Phys. Rev. **52**, 63; **52**, 610 (1937).
[3] Laslett and Hurst, Phys. Rev. **52**, 1035 (1937).
[4] Skobeltzyn and Stepanowa, Nature **137**, 234 (1935); Leprince-Ringuet, Ann. de physique **7**, 5 (1937); Klarmann and Bothe, Zeits. f. Physik **101**, 489 (1936).
[5] Crane, Rev. Sci. Inst. **8**, 440 (1937).

High energy group

As a source of high energy positrons and electrons, we used the gamma-radiation emitted in the $Li+H^1$ reaction.[6] The protons were accelerated by the high voltage apparatus previously described.[7] The gamma-rays coming from the lithium target struck a sheet of lead about 3 mm thick which was placed against the inside wall of the cloud chamber. The pairs emerging from the lead passed through an absorber of lead, 0.038 cm thick, placed across the center of the chamber. The magnetic field had a value of 2850 oersteds±2 percent.

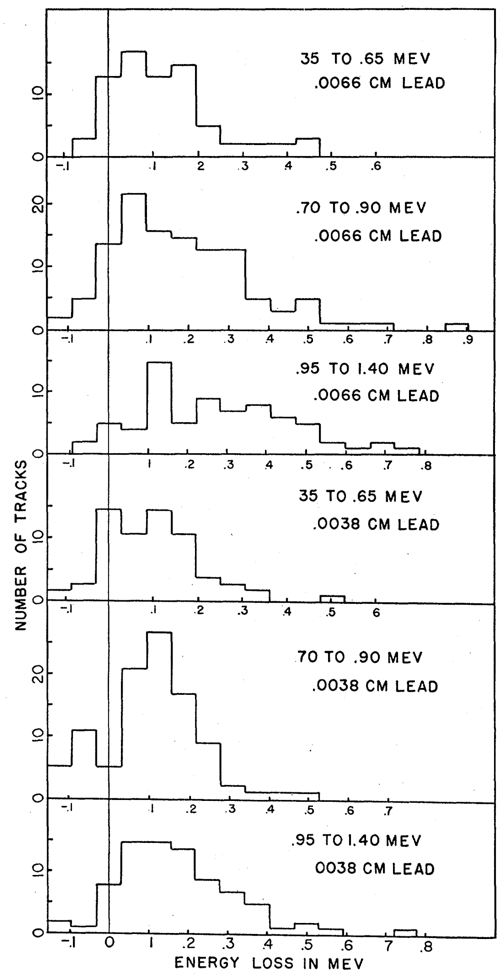

FIG. 1. Energy losses for electrons traversing lead laminae of thicknesses 0.0038 cm and 0.0066 cm.

[6] Gaerttner and Crane, Phys. Rev. **52**, 582 (1937); Delsasso, Fowler and Lauritsen, Phys. Rev. **51**, 391 (1937).
[7] Crane, Phys. Rev. **52**, 11 (1937).

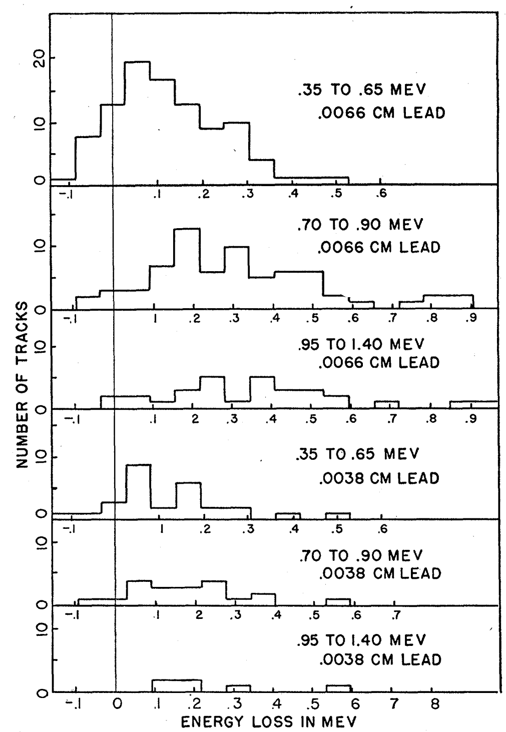

FIG. 2. Energy losses for electrons reflected from lead laminae of thicknesses 0.0038 cm and 0.0066 cm.

RESULTS

Histograms showing the distribution of energy losses among the electrons for the groups of various energies are plotted in Figs. 1 to 4. A summary of the energy loss data obtained from these histograms is given in Tables I to V. In Table I the losses for the two different thicknesses of lead are in good agreement, being about 10 percent higher for the thinner absorber. The energy loss per unit length has not been given for the reflected electrons in Tables II and V, since there is no way to estimate the minimum

TABLE I. *Energy losses of electrons traversing lead absorbers.*

THICKNESS OF ABSORBER	NUMBER OF ELECTRONS	ENERGY RANGE IN MEV	AVERAGE ENERGY IN MEV	AVERAGE LOSS IN MEV/CM	THEORETICAL LOSS IN MEV/CM
	69	0.35 to 0.65	0.55	23	11
0.0038 cm	101	0.7 to 0.9	0.79	28	11
	81	0.95 to 1.4	1.08	48	11
	251		0.82	33	11
	61	0.35 to 0.65	0.57	19	11
0.0066 cm	117	0.7 to 0.9	0.80	27	11
	71	0.95 to 1.4	1.08	44	11
	249		0.82	30	11

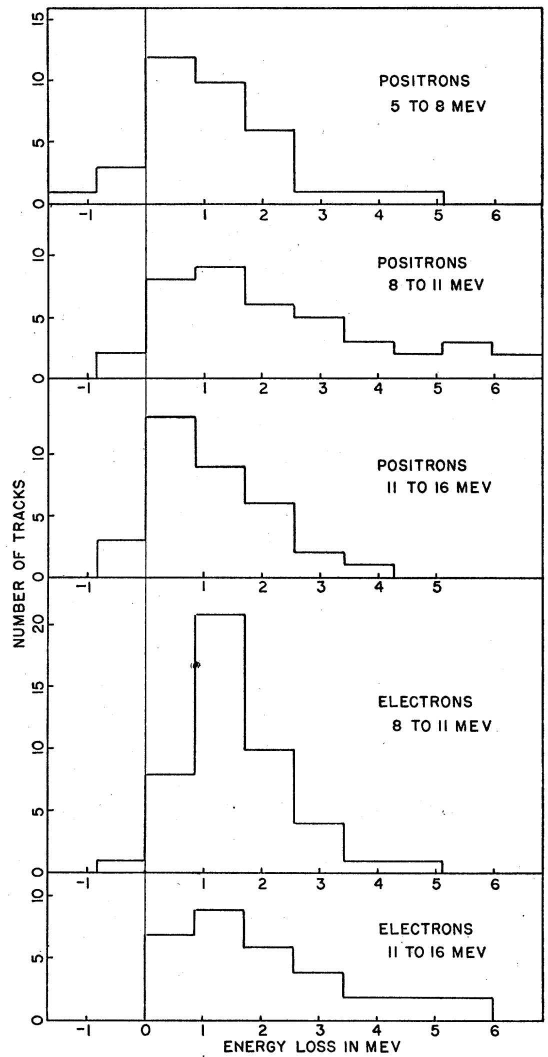

FIG. 3. Energy losses of positrons and of electrons traversing a lead lamina of thickness 0.038 cm.

length of path within the absorber of such reflected particles. The reflections summarized in Table V were obtained from the photographs which were taken for the previous investigation of the energy losses of Li^8 beta-rays.[2] The values predicted by theory[8] are also given in the tables for comparison.

Discussion

For electrons below 1 Mev the radiation losses indicated by the Bethe-Heitler theory are negligible, even in lead. The energy losses should

[8] Heitler, *Quantum Theory of Radiation*, p. 217.

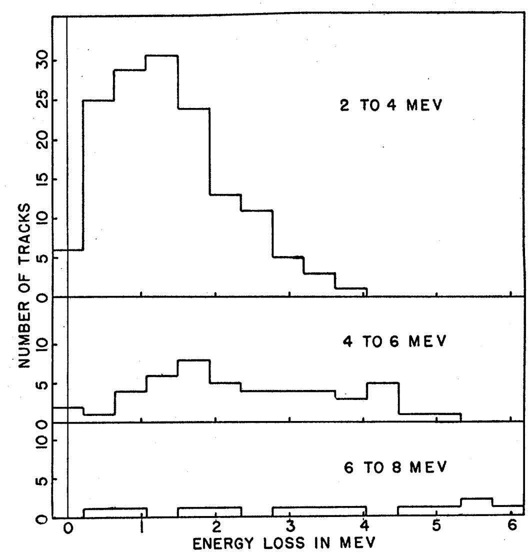

FIG. 4. Energy losses of electrons reflected from a lead lamina of thickness 0.05 cm.

be due almost entirely to ionization processes, and should therefore not change markedly with incident energy. For this reason the sharp increase which we observe in energy loss for 1 Mev electrons as compared to the loss for 0.5 Mev electrons is difficult to interpret. Because this increase occurs for both thicknesses of absorber and for both traversals and reflections it is hard to doubt its reality. If the actual thickness of the absorber should be multiplied

TABLE II. *Energy losses of electrons reflected from lead absorbers.*

Thickness of Absorber	Number of Electrons	Energy Range in Mev	Average Energy in Mev	Average Energy Loss in Mev
0.0038 cm	28 20 6	0.35 to 0.65 0.7 to 0.9 0.95 to 1.4	0.56 0.77 1.04	0.13 0.18 0.26
	54		0.69	0.16
0.0066 cm	98 69 31	0.35 to 0.65 0.7 to 0.9 0.95 to 1.4	0.59 0.79 1.07	0.13 0.30 0.38
	198		0.73	0.23

TABLE III. *Energy losses of positrons traversing lead.*

Thickness of Absorber	Number of Positrons	Energy Range in Mev	Average Energy in Mev	Average Loss in Mev/cm	Theoretical Energy Loss in Mev/cm
0.038 cm	35 47 33	5 to 8 8 to 11 11 to 16	5.8 9.5 12.3	30 40 49	21 28 33

by some factor larger than unity because of the increase in path length in the absorber due to scattering, we would expect this factor to be larger for the lower energy group, since scattering increases greatly with decreasing energy. Thus the actual increase in energy loss more than compensates for this factor.

It might be supposed that for some reason the large losses of the lowest energy group are not considered in the data. This might be due to the fact that tracks of very small radii of curvature are more easily missed in the cloud chamber or discarded because of scattering. Or again, it could be because of a smaller probability for particles which have lost most of their energy emerging from the lead absorber. If this were so, however, the fractional losses would be appreciably higher for the 1 Mev electrons than for those with less energy (unless there are some compensating factors). But experimentally there are no appreciable differences in fractional losses among the three energy groups.

In addition to the variation of energy loss with energy the data indicate an experimental loss which is about three times the value given by the Bloch formula. This agrees with the work of Laslett and Hurst,[3] who found a factor 2.6 times theory in the region from 1.5 to 4.5 Mev. Whether this can be accounted for on the basis of an increase in path length in the absorber due to multiple scattering cannot be answered at present. If one postulates that there are large radiative losses already for electrons below 1 Mev, this might be difficult to reconcile with experiences regarding the efficiency of high voltage x-ray tubes.

TABLE IV. *Energy losses of electrons traversing lead.*

THICKNESS OF ABSORBER	NUMBER OF ELECTRONS	ENERGY RANGE IN MEV	AVERAGE ENERGY IN MEV	AVERAGE LOSS IN MEV/CM	THEORETICAL ENERGY LOSS IN MEV/CM
0.038 cm	33	8 to 11	9.5	34	28
	41	11 to 16	12.7	61	34

TABLE V. *Energy losses of electrons reflected from lead.*

THICKNESS OF ABSORBER	NUMBER OF ELECTRONS	ENERGY RANGE IN MEV	AVERAGE ENERGY LOSS IN MEV
0.05 cm	146	2 to 4	1.30
	50	4 to 6	2.38
	12	6 to 8	3.47

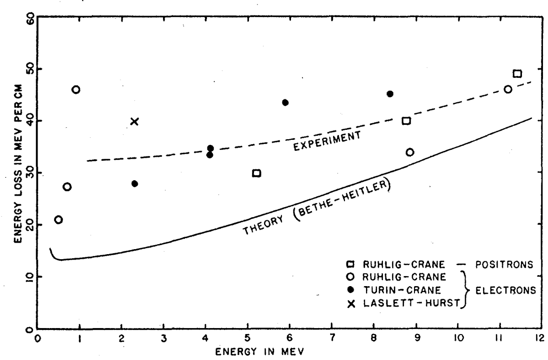

FIG. 5. Differential energy loss of positrons and electrons in lead for various incident energies, compared to theoretical values.

The values found here for high energy electrons and positrons are in good agreement with those previously reported. We have summarized the experimental values for energy losses in lead in Fig. 5. It is seen that the experimental values are appreciably higher than theory, but theory may be as much as 30 percent too low because of the approximations made in the derivation. We have not found any marked difference between the losses of positrons and those of electrons, as were indicated for the cosmic-ray region by Crussard.[9] This is in agreement with the work of Anderson and Neddermeyer[10] and Blackett and Wilson[11] in the cosmic-ray region, and with the results of Curtis[12] for the losses of low energy positrons in aluminum.

In the fourth part of this series of papers, now being prepared by M. M. Slawsky and H. R. Crane, there will be presented experimental data on multiple scattering for the energy range for which loss measurements have been made, and an attempt will be made to discover whether the effects of scattering are sufficient to account for the observed energy loss.

We wish to thank Professor J. M. Cork, Dr. R. L. Thornton and the other members of the Michigan cyclotron group for supplying the radioactive phosphorus. This research was made possible through the generosity of the Horace H. Rackham Foundation.

[9] Crussard, J. de phys. **8**, 213 (1937).
[10] Anderson and Neddermeyer, Phys. Rev. **51**, 884 (1937).
[11] Blackett and Wilson, Proc. Roy. Soc. **A160**, 304 (1937).
[12] Curtis, Phys. Rev. **53**, 206 (1938).