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# Further Experiments on the Elastic Single Scattering of Electrons by Nuclei*

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The apparatus used in making the observations previously reported has been reassembled, and the measurements have been extended to lower atomic number by using beryllium as a scattering material. These show that, for angles up to 60° and for electron energies of 2.1, 2.2, and 2.3 Mev, the ratio of observed scattering to that predicted by the Mott formula is 0.99, with a standard deviation of 0.04. Measurements have also been made on aluminum in this angular and energy range, and the ratio of observed scattering to that predicted is found to be 0.99 with a standard deviation of 0.05. The earlier results for aluminum at 2.27 Mev, which were reported as anomalous and to be repeated, were presumably due to experimental errors of undetermined origin. The present results, together with those reported earlier, show that, in this angular and energy range, the elastic single scattering of electrons is in good agreement with theory for nuclei ranging in atomic number from 4 to 79 (beryllium to gold).

## 1. INTRODUCTION

IN an earlier paper,[1] we reported some measurements on the elastic scattering of electrons by nuclei in the energy range from 1.27 to 2.27 Mev. The nuclei investigated in those experiments were aluminum, copper, silver, platinum, and gold. It was found that, except for the case of 2.27-Mev electrons on aluminum, the results were in close agreement with the relativistic theory of electron scattering as developed by Mott. In order to extend the measurements to lower atomic number as well as to check the anomalous results previously obtained for the scattering of 2.27-Mev electrons by aluminum, the apparatus previously used has been modified somewhat and reassembled.

## 2. APPARATUS

The use of the electrostatic accelerator for other purposes during the war has led to certain improvements in the technique of accelerating and focusing the electron beam. Among these was the installation of an annular focusing magnet at the grounded end of the accelerating tube and the development of a small-area cathode for use as the electron source. This combination allows precise control of the diameter of the electron beam over the range from 0.010 to 0.250 inch. Both the position and the potential of the electron source with respect to the electrodes of the accelerating tube were controlled by selsyn motors located at the remote-control panel. These arrangements were particularly useful in the experiment in insuring that the beam passed completely through the entrance diaphragms to the scattering chamber, thus eliminating a possible source of x-ray background.

Another source of x-ray background is that produced by electrons which are scattered by the foil and which subsequently strike the walls of the scattering chamber. This is principally caused by small-angle scattering. It has been very much reduced in the present experiment by placing a layer of beryllium one-eighth inch thick on the inside cylindrical wall of the scattering chamber. This beryllium covering extended up to an angle of about 30° on both sides of the incident electron beam.

As in the preceding experiments, the target foils were mounted around the rim of an insulated aluminum disk. For the present experiment, selsyn motors were mounted on the lid of the scattering chamber so that this target holder could be both accurately rotated and tipped with respect to the electron beam by using selsyns located at the remote-control panel. This facilitated the changing of targets and the rapid intercomparison of results for different atomic numbers and different foil thicknesses. In addition, rotation of the foil carrier made it possible to make scattering measurements using different areas of the same foil while the effective thickness of the foil was varied by changing its angle with respect to the electron beam.

* A preliminary account of this work was given in an abstract at the November 30, 1946 meeting of the American Physical Society in Minneapolis, Phys. Rev. **71**, 142 (1947).

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[1] R. J. Van de Graaff, W. W. Buechner, and H. Feshbach, Phys. Rev. **69**, 452 (1946).

The collector assembly with ionization chamber was the one previously employed. The one-eighth inch thick beryllium layer placed over the lower part of the walls of the scattering chamber made it necessary to move the ionization chamber assembly somewhat closer to the scattering foil. The solid angle corresponding to the entrance window to the ionization chamber has thus been increased to $7.87\times10^{-3}$ steradians. As in the previous experiments, a relatively thick absorber was placed immediately in front of the ionization chamber to stop any electrons that might have been scattered from the primary beam with a loss of energy due either to electron-electron or to inelastic nuclear scattering. In the present case, the absorber used was a 0.033 inch thick sheet of copper. The total material in the path of the scattered electrons (absorber plus the window of the ionization chamber) amounted to slightly less than the range of 2.0-Mev electrons, the lowest energy employed in the present measurements.

The experimental procedure followed in calibrating the ionization chamber and in making the experimental measurements was identical with that previously described. Since the reduction in background made it possible to increase the sensitivity of the apparatus, a Lindemann electrometer with calibrated high resistors was used for making the ionization current measurements. This made it possible to extend the angular range of the measurements up to 60°.

### 3. RESULTS

Measurements have been made with beryllium and aluminum foils as scattering materials. As in the previous paper, the results of these experiments, after the various corrections outlined there were made, have been compared to the predictions of the Mott theory. The ratios of these experimental results to the theoretical predictions are given in Table I.

The measurements on beryllium were made with a foil that was 0.0037 inch thick. This foil was of exceptional purity. The results given in the table show that, for angles up to 60° and for electron energies of 2.1, 2.2, and 2.3 Mev, the ratio of the observed scattering for beryllium to that predicted by the theory is 0.99, with a standard deviation of 0.04.

TABLE I. Ratios of measured elastic scattering of electrons to predictions of Mott's theory.

| Energy (Mev) | 35° | 40° | 45° | 50° | 55° | 60° |
|---|---|---|---|---|---|---|
| | | | Nucleus: beryllium | | | |
| 2.1 | 1.02 | 0.98 | 0.93 | 1.00 | 0.97 | 0.93 |
| 2.2 | 0.97 | 0.98 | 0.96 | 0.99 | 0.99 | 1.11 |
| 2.3 | 0.98 | 1.00 | 1.01 | 1.00 | 0.99 | 1.02 |
| | | | Nucleus: aluminum | | | |
| 2.1 | 0.94 | 0.94 | 0.94 | 0.93 | 0.95 | 0.91 |
| 2.2 | 1.00 | 1.02 | 1.03 | 1.06 | 1.02 | 1.03 |
| 2.3 | 1.02 | 1.00 | 1.05 | 0.99 | 1.04 | 1.00 |

In view of some of our previous results for aluminum, very careful measurements have been made for this element in this angular and energy range. Particular attention was given to the scattering obtained from the same aluminum foils that were used in the previous work. Our present measurements show that, for angles up to 60° and voltages from 2.0 to 2.3 Mev, the scattering from aluminum is in good agreement with theory, the ratio of observed scattering to that predicted being 0.99 with a standard deviation of 0.05.

### 4. DISCUSSION

In the previous paper, we reported that, except for the case of 2.27-Mev electrons on aluminum, the results obtained over a wide range of experimental variables were in close agreement with theory. This agreement was in marked contrast with the results of most previous observers who have reported wide divergence from theory. The anomalous results with aluminum were among the last obtained before that apparatus was dismantled. In view of the present careful measurements on both the old foils and the new ones, we can only conclude that the anomalous result for this particular element and energy was due to experimental errors, for which we are as yet unable to ascribe an origin. The present results, together with the earlier ones, show that, for angles up to 60° and for energies up to 2.3 Mev, the elastic single scattering of electrons is in good agreement with theory for nuclei ranging in atomic number from 4 to 79 (beryllium to gold).

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