High-Energy Electron Scattering by Nuclei*

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The Michigan race-track synchrotron has been used as a source of electrons for the study of elastic scattering of 30- to 45-Mev electrons by nuclei of $Z=46-52$ and $Z=74$. The experimental results for tungsten can be interpreted to give a value of the nuclear radius equal to $(1.0\pm0.1)\times10^{-13}A^{\frac{1}{3}}$ cm if a constant proton density is assumed for the nucleus. The radius of the tin nucleus is $(1.1\pm0.1)\times10^{-13}A^{\frac{1}{3}}$ cm. Any discontinuity in r_0 *versus* A at the closing of the $g_{9/2}$ shell is about 1 percent or less; a step increase of 2 percent at $Z=48$ gives a best fit to the lower Z data.

INTRODUCTION

THE angular dependence of the differential cross section for the scattering of electrons by nuclei depends on the nuclear charge distribution when the electron de Broglie wavelength is comparable with the nuclear size. Several measurements of the cross section have been made at incident electron energies between 30 and 45 Mev. The results for a tungsten target are in agreement with a nuclear radius given by $R=r_0A^{\frac{1}{3}}$, $r_0=(1.0\pm0.1)\times10^{-13}$ cm, for an assumed uniform spherical model of the nucleus. A somewhat larger value of r_0 is found for tin and neighboring elements. A comparison of these radii with the values obtained by other means shows the inadequacy of the simple uniform model and to some extent how it should be modified.

APPARATUS

The source of electrons is the internal beam of the Michigan synchrotron. A target is located in one of the field-free straight sections at a position just inside the equilibrium beam orbit. The beam is scattered by contracting the orbit to the target radius. Figure 1 shows the equilibrium orbit, target location, and the detecting systems.[1] Scattered electrons emerge from the vacuum chamber through 5-mil aluminum windows into the detecting systems on either side of the chamber. One detector fixed at 90° is used as an intensity monitor, while the other can be set at angles between 60° and 120° with respect to the incident beam direction. The detecting systems include a collimator, magnetic analyzer, and a pair of shielded Geiger counters, all shown approximately to scale in the figure. The scattered beam is deflected through an angle of 15° in the anlayzer magnetic field and then is detected as a coincidence in the pair of counters. Background coincidences are recorded in either of two ways, by plugging the collimator hole or by increasing the analyzer field so that electrons elastically scattered from the target cannot reach the counters. Both methods give the same result. A typical spectrum of the scattered electrons shows a symmetrical peak centered at the incident beam energy, an energy half-width of ±20 percent, and a height about 10 times the background level. The counting rate is adjusted to about $\frac{1}{8}$ count per synchrotron pulse. All data are corrected for systematic counting errors.

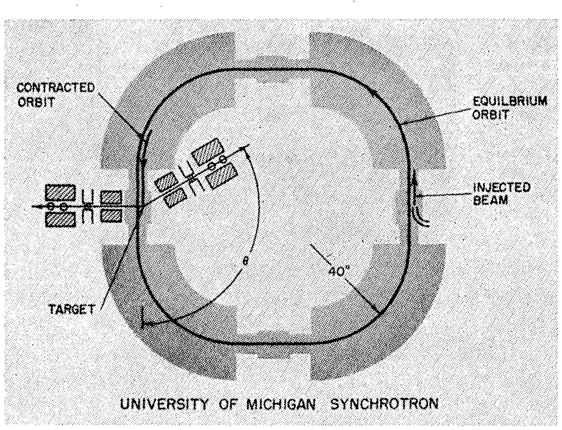

FIG. 1. Experimental layout.

EXPERIMENTAL RESULTS

In Fig. 2 are plotted the cross sections for a tungsten target at 33 Mev. For comparison, theoretical curves for 30-Mev electrons are drawn for a point nucleus[2] and a uniform speherical model,[3] $r_0=1.45\times10^{-13}$ cm. Both data and curves are normalized at 90°. It can be seen that the experimental points deviate from the uniform model toward the point nucleus. A choice of $r_0=1.0\times10^{-13}$ cm, about 30 percent smaller than the assumed value, leads to the best agreement between data and calculation. In this range of energies, the cross section is a function of the product of electron energy and nuclear radius. Therefore the uniform sphere prediction for $E=30$ Mev, $r_0=1.45\times10^{-13}$ cm, applies equally well for the combination, $E=43$ Mev, $r_0=1.0\times10^{-13}$ cm. The data obtained at 43 Mev, plotted in the same graph, are in much better agreement with this predicted angular distribution than the 33-Mev points.

The systematic errors in the experimental cross

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[1] Raka, Hammer, and Pidd, Phys. Rev. 90, 341 (1953).

[2] H. Feshbach, Phys. Rev. 88, 295 (1952).

[3] L. K. Acheson, Jr., Phys. Rev. 82, 488 (1951).

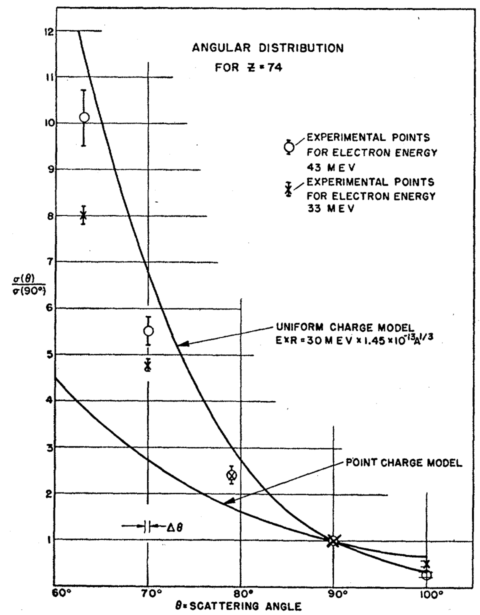

FIG. 2. Differential cross sections for tungsten.

sections are considerably less than the standard deviations which are shown. The tungsten target is 0.007 inch thick and is oriented at 45° with respect to the incident beam direction. The variable-angle detector is on the transmitting side of the target. Relative corrections depending on the target thickness at angles between 60° and 100° are less than 2 percent. The errors include corrections for multiple and plural scattering, and straggling in the target. At angles larger than 100° these errors become much larger especially due to plural scattering and the data are not considered reliable. Thus the conclusions reached in the preceding paragraph refer to the more reliable forward angles. The error calculations are confirmed experimentally by a repeat run with the target thickness reduced by one-half, in which no detectable change in the cross sections could be observed. The Schwinger correction, while important to the absolute cross section, would lead to a negligible differential correction within the angular range in the experiment.

Similar data have been obtained for a series of target elements from $Z=46$ to $Z=52$ at an energy of 34 Mev. In an effort to find any systematic differences from element to element, the targets were alternated inside the vacuum system in a series of runs so that any experimental bias could be minimized. A total of 12 500 counts was accumulated for each element at two angles, 60° and 90°. The ratios, $\sigma(60°)/\sigma(90°)$ are plotted in Fig. 3. The ratio predicted for a point nucleus[2] is 5.2 and for a uniform sphere,[3] $r_0=1.45\times10^{-13}$ cm, about 11 for all the elements. The value $r_0=(1.1\pm0.1)\times10^{-13}$ cm is consistent with the data, 10 percent larger than in the case of tungsten. Individual variations among the target elements are less than the standard deviation except for the break between $Z=48$ and $Z=49$.

CONCLUSIONS

Coefficients of the nuclear radius less than 1.45×10^{-13} cm have been found in other experimental work. In particular, electron scattering at 15.7 Mev,[4] and μ-meson absorption by nuclei[5] agree with a value of 1.2×10^{-13} cm. It appears from this that observations which depend only on the electric charge distribution in the nucleus may give a consistently smaller value for the nuclear size than the value obtained from reactions which depend on nuclear interaction. The data on beta decay of mirror nuclei, on the other hand, are consistent with the larger value of the radius, if the uniform model is used. Since these data extend only up to $Z=20$ they cannot be readily compared with electron scattering results now available.

Methods of measuring the nuclear size which are available at present fail to determine a nuclear model. In each case they measure an effective radius for an interaction and not a nuclear density distribution. It

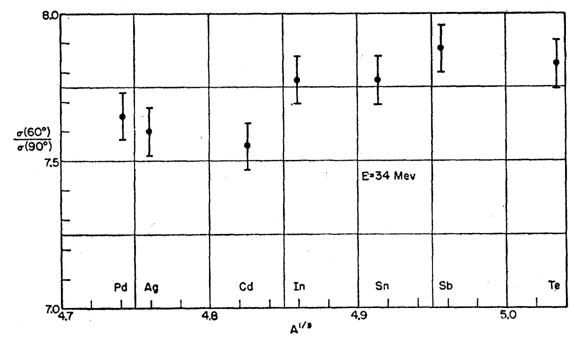

FIG. 3. Ratios of differential cross sections at 60° and 90° for elements from $Z=46$ to $Z=52$.

is not surprising then that different observations and different interactions should give conflicting results when interpreted on the basis of a uniform model with a sharp boundary. Nevertheless, saturation in nuclear structure is a common point of agreement among all measurements and any new model must retain this property. In view of this, the nuclear model suggested by Wilson,[6] a saturated core surrounded by an exponentially decreasing distribution, may lead to the best agreement among all data on the nuclear size. Some scattering models such as this have been used and they show that the angular dependence of the cross section for electron scattering depends mostly on the core size. It is possible that the radius measured by neutron scattering, for example, would extend toward the edge of the distribution. Electron scattering at much higher energies is model-dependent and should yield more detailed information about the shape of the proton distribution in the nucleus.

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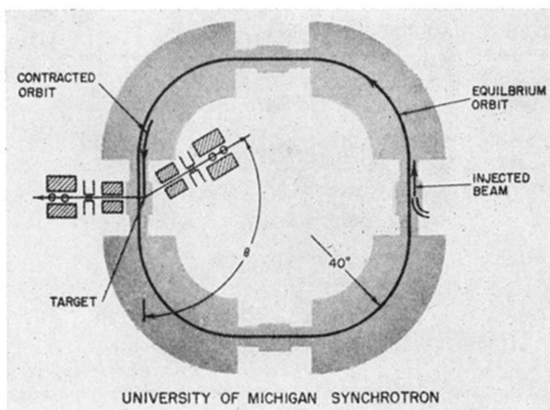
[5] L. N. Cooper and E. M. Henley, Bull. Am. Phys. Soc. **28**, No. 3, 56 (1953).
[6] R. R. Wilson, Phys. Rev. **88**, 350 (1952).



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