Spins and Parities of Energy Levels in Pb^{208}

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MEASUREMENTS of the K internal conversion coefficients α_K of the 2.62, 0.583, 0.860, and 0.511 Mev γ-ray transitions in Pb^{208} following the decay of Tl^{208} (3.1 min) together with a determination of the angular correlations between selected pairs of these γ rays have recently been made at this laboratory. The results lead unambiguously to the spin and parity assignments shown in Fig. 1 with the sole assumption of zero spin and even parity for the ground state of Pb^{208}.

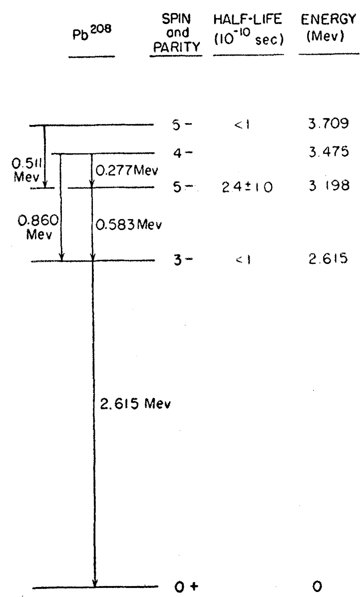

FIG. 1. Spins and parities of energy levels in Pb^{208}.

The α_K for the 2.62-Mev transition was found by measuring separately the quantum intensity q, and K internal conversion electron intensity e_K from a source of thorium active deposit. The q was found by comparison with the quantum intensity of the 2.76-Mev γ radiation from a standardized source of Na^{24} using a NaI(Tl) scintillation spectrometer. The e_K was determined by measurement of the "X" line intensity in a magnetic β-ray spectrometer having an accurately measured transmission. The α_K for the 0.583-Mev transition was found in a similar manner. The values obtained were $(1.78\pm0.12)\times10^{-3}$ and $(1.52\pm0.11)\times10^{-2}$ for the 2.62-Mev and 0.583-Mev transitions, respectively. The former is in good agreement with the theoretical value[1] of 1.86×10^{-3} for $E3$ radiation and the latter with the theoretical value[1] of 1.61×10^{-2} for $E2$ radiation. Both measured values are in agreement with those reported by Martin and Richardson.[2]

The angular correlation experiment was performed using a source of thorium active deposit in a $1N$ nitric acid solution with a small amount of $Pb(NO_3)_2$ added as carrier. The detectors were NaI(Tl) crystals and 6292 Dumont or 5819 RCA photomultipliers. Each channel of the coincidence circuit incorporated a single-channel pulse-height analyzer. By appropriate pulse-height selection coincidences between the 0.511-Mev γ ray and the 2.62-Mev γ ray were avoided entirely. Except for a 3 percent contribution caused by the Compton effect from the 0.860-Mev transition the true coincidences recorded were due entirely to those of the 0.583-Mev and 2.62-Mev cascade.

Coincidences were recorded at seven angles and the rates, corrected for (1) chance coincidences, (2) the contribution owing to the 0.860-Mev transition, and (3) the decay of the sample, are shown in Fig. 2. The experimental data are plotted as points, normalized to the value at 90°. The curves are the theoretical functions (corrected for the finite angular resolution) for the 0–3–5 assignment and the previously proposed assignments[2,3] 0–2–4 and 0–1–3. The experimental results are consistent only with the assignment 0–3–5.

Similar but less detailed measurements of α_K for the 0.86-Mev and 0.511-Mev γ rays and of the angular correlations of these γ

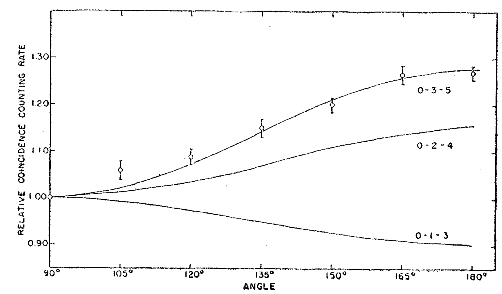

FIG. 2. Angular correlation between the 0.583-Mev and 2.615-Mev γ rays. The experimental data are plotted as points normalized to the value at 90°. The vertical bars represent the standard deviations. The curves are the theoretical functions corrected for the finite angular resolution for the assignments 0–3–5, 0–2–4, and 0–1–3.

rays with respect to the 2.62-Mev γ ray indicate: (1) an assignment of 4− for the 3.48-Mev level with an intensity ratio of $E2/M1=(6.5\pm6.5)\times10^{-4}$ and 180° phase difference for the 0.86-Mev γ ray, and (2) an assignment of 5− for the 3.71-Mev level with $E2/M1=1.7\pm0.3$ and 0° phase difference for the 0.511-Mev γ ray.

Coincidences were observed in a double magnetic β-ray spectrometer between the β-ray continuum and the 0.583-Mev K internal conversion line, and indicate that the 0.583-Mev transition is delayed with a half-life of $(2.4\pm1.0)\times10^{-10}$ sec. Observed coincidences between the 0.583-Mev γ ray and the 2.62-Mev γ ray indicate a half-life of less than 1×10^{-10} sec. An upper limit of 1×10^{-10} sec for the half-life of the 0.511-Mev transition has also been obtained. These data are incorporated in Fig. 1.

A detailed investigation of the decay of Tl^{208} is being carried out and a complete report will be submitted for publication in the *Canadian Journal of Physics*.

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[1] Rose, Goertzel, and Perry, Oak Ridge National Laboratory Report ORNL-1023, 1951 (unpublished).
[2] D. G. E. Martin and H. O. W. Richardson, Proc. Phys. Soc. (London) A63, 223 (1950).
[3] H. E. Petch and M. W. Johns, Phys. Rev. 80, 478 (1950).

Elastic Scattering of Intermediate-Energy Alpha Particles by Gold*

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THE elastic scattering by Au of alpha particles of energies 14 to 42 Mev has recently been observed in this laboratory. The variation of cross section with alpha-particle energy has been studied for scattering angles of 60° and 95° (lab system). At low bombarding energies, the cross section is given by the Rutherford formula for Coulomb scattering; at higher energies, the decrease in cross section with increasing alpha-particle energy is much more rapid.

The distance of closest approach of alpha particle and scattering nucleus, or apsidal distance, can be calculated for the classical trajectory of an alpha particle of a given energy scattered through a particular angle. For the energy $E_\alpha{}^0$ (hereinafter called the critical energy) at which the deviation from Coulomb scattering is first observed, the apsidal distance is found to be $(12.5 \pm 0.2) \times 10^{-13}$ cm for the 60° case. This distance is significantly larger than a reasonable estimate ($9-10 \times 10^{-13}$ cm) of the sum of the radii of the Au nucleus and the alpha particle.[1] A similar value, $(12.9 \pm 0.3) \times 10^{-13}$ cm, is found for the apsidal distance at the critical energy in the 95° case.

Departures from Coulomb's law were observed by Bieler,[2] who studied the angular distribution of alphas scattered by Mg and

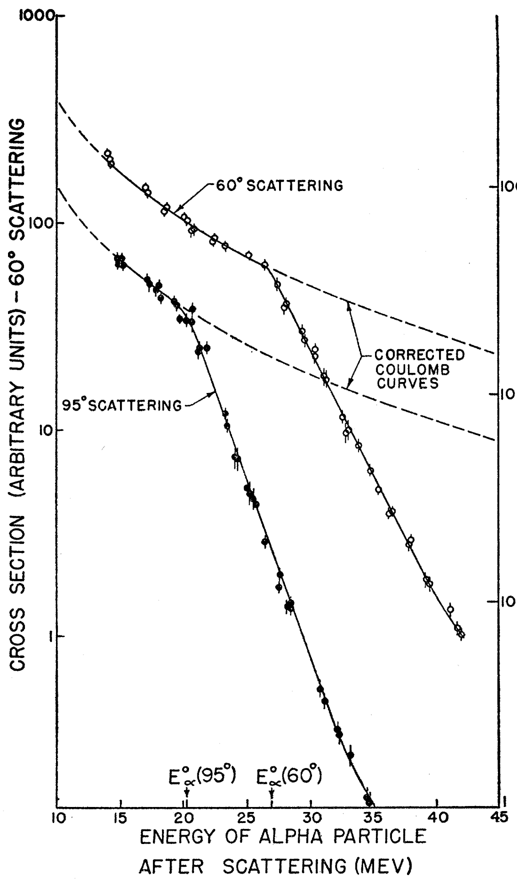

FIG. 1. Elastic scattering of alpha particles by gold. Cross section (relative) is plotted against alpha-particle energy for 60° scattering and for 95° scattering. The low-energy part of each curve is normalized to a corrected Coulomb curve (see text). The critical energy $E_\alpha{}^0$ corresponds to the intercept of the straight line portion of the experimental curve with the corrected Coulomb curve.

Al, and by Rutherford and Chadwick,[3] who measured the dependence of elastic-scattering cross section upon alpha energy for Al. Data in the non-Coulomb region were very meager because of the limited range of alpha energy available, and interest in the elastic scattering of alphas by intermediate and heavy nuclei seems to have lapsed after these experiments.

The deflected alpha-particle beam of the University of Washington 60-in. cyclotron was used in the present experiments. A remotely controlled absorber was installed which could reduce the incident alpha-particle energy from 42 Mev to zero in steps of about 1 Mev. Scattered alpha particles were observed by means of a differential-range coincidence proportional-counter telescope. At each value of the incident alpha-particle energy, the number of elastically scattered alpha particles observed was normalized to the integrated beam current.

Results are shown in Fig. 1. For each scattering angle, relative elastic-scattering cross section is plotted against alpha-particle energy after scattering. Each curve is normalized to a "corrected Coulomb curve," i.e., a curve in which the energy dependence predicted by the Rutherford formula is modified very slightly to take into account a small variation in scattering angle with energy. (This variation is due to the fringing magnetic field of the cyclotron.)

At low energies, the cross section at 60° is seen to follow the Coulomb dependence closely. At an energy of about 27 Mev, however, the cross section begins to drop very rapidly as the alpha-particle energy E_α is increased. The energy dependence in the range 27–40 Mev is very well represented by the simple empirical formula:

$$\sigma(E_\alpha) = \sigma(E_\alpha{}^0) \exp\{-K(E_\alpha - E_\alpha{}^0)\},$$

where $\sigma(E_\alpha)$ = cross section at energy E_α (Mev), $E_\alpha{}^0$ = critical energy = 27.0 ± 0.3 Mev, and K = constant = 0.28 Mev^{-1}.

The curve for scattering through 90° is similar in form, the critical energy $E_\alpha{}^0$ being lower (20.25 ± 0.4 Mev) and K being higher (0.40 Mev^{-1}).

Studies are in progress using other heavy elements. Preliminary results are very similar to those for Au. The critical energy $E_\alpha{}^0$ increases with Z but the parameter K appears to be independent of Z (for a particular scattering angle) within the experimental uncertainties.

Since $E_\alpha{}^0$ and the corresponding apsidal distance can be measured quite precisely, it seems likely that these experiments offer a sensitive means of detecting small differences in nuclear size, and we expect to explore this aspect. It is evident that strong absorption occurs when nuclear forces come into play at apsidal distances comparable to the nuclear radius. A theoretical analysis of the present results and others to be obtained should give more exact information on the nature of the interaction between alpha particles and heavy nuclei and on effective nuclear and alpha particle radii.

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[1] Use of $R_n = r_0 A^{\frac{1}{3}}$, with $r_0 = 1.4 \times 10^{-13}$ cm, gives for the radius of the Au nucleus the value $R_n = 8.1 \times 10^{-13}$ cm. Following J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley and Sons, Inc., New York, 1952), a value $R_\alpha = 1.2 \times 10^{-13}$ cm is assumed here for the effective alpha-particle radius.

[2] E. S. Bieler, Proc. Roy. Soc. (London) **A105**, 434 (1924).

[3] E. Rutherford and J. Chadwick, Phil. Mag. **50**, 889 (1925).

Proton Distribution in Heavy Nuclei*

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THE Coulomb repulsion tends to force protons as far apart as possible, thereby lowering the proton density at the center of a nucleus. One might conclude that such an expansion would cause a proton excess on the nuclear surface. It is easy to see that the stability against β decay brings about the opposite result, a neutron excess on the surface.

The top part of Fig. 1 gives a qualitative picture of the average potential acting on neutrons and protons. It is assumed that the proton potential and the neutron potential are the same except for the electrostatic energy. The dashed line indicates the highest filled energy state in the Fermi distribution for both protons and neutrons. Beta stability requires that the highest filled proton state have the same energy as the highest filled neutron state (actually the proton should have 0.79 Mev more energy, a difference that may be neglected compared to the Coulomb potential in heavy nuclei). If the nuclear potential at the surface has a finite slope, the dashed line intercepts the potential at a somewhat smaller radius for protons. Consequently, the proton