the energy shift of the extranucleons' energy levels (the unperturbed levels being those of the spherical core case). Owing to the strong spin-orbit coupling (1) the zero-approximation eigenfunctions are given by the well-known formulas:

$$\begin{aligned}\psi_{n,l,l-\frac{1}{2},m}&=[\rho_{n,l}(r)/(2l+1)^{\frac{1}{2}}]\{(l+\tfrac{1}{2}-m)^{\frac{1}{2}}Y_{l,m-\frac{1}{2}}(\vartheta,\varphi)\alpha(\sigma)\\&\qquad-(l+\tfrac{1}{2}+m)^{\frac{1}{2}}Y_{l,m+\frac{1}{2}}(\vartheta,\varphi)\beta(\sigma)\},\\ \psi_{n,l,l+\frac{1}{2},m}&=[\rho_{n,l}(r)/(2l+1)^{\frac{1}{2}}]\{(l+\tfrac{1}{2}+m)^{\frac{1}{2}}Y_{l,m-\frac{1}{2}}(\vartheta,\varphi)\alpha(\sigma)\\&\qquad+(l+\tfrac{1}{2}-m)^{\frac{1}{2}}Y_{l,m+\frac{1}{2}}(\vartheta,\varphi)\beta(\sigma)\},\end{aligned}\tag{3}$$

where $\rho_{n,l}(r)$ is the radial part of the wave function.

The perturbation calculation yields for the energy shift relative to the unperturbed energy level $E_{n,l,j,m}$:

$$\Delta E_{n,l,j,m}=-\frac{\hbar^2x_{n,l}^2}{MR_0^2}\left\{\alpha_2\frac{j(j+1)-3m^2}{4j(j+1)}+\alpha_4\frac{3}{64}\frac{3m^4-5m^2[6j(j+1)-5]+3j(j^2-1)(j+2)}{j(j^2-1)(j+2)}\right\},\tag{4}$$

where $x_{n,l}$ is the $n$th zero of the Bessel function of order $l+\frac{1}{2}$, $M$ the mass of the extranucleon, and only the first two nonvanishing coefficients of the $\alpha$'s have been retained.

This result, together with the Bohr-Wheeler formula giving the electrostatic and surface energies of the core, allows a calculation of the equilibrium shape of the nucleus and of the corresponding total energy variation.

The nuclei we consider are supposed to be heavy enough so that both assumptions, of adiabatic rotation of the core with respect to the extranucleons' motion and of applicability of the liquid drop model, are permissible.

For $N+P$ extranucleons the equilibrium shape is defined by the following values of the deformation parameters:

$$\bar{\alpha}_2=\frac{\hbar^2}{4\pi R_0^4\tau M}\sum_{k=1}^{N+P}x_{n_k,l_k}^2I_{j_k,m_k,2}/[4(1-x)/5];$$

$$I_{j_k,m_k,2}=j_k(j_k+1)-3m_k^2/4j_k(j_k+1),$$

$$\bar{\alpha}_4=\frac{\hbar^2}{4\pi R_0^4\tau M}\sum_{k=1}^{N+P}x_{n_k,l_k}^2I_{j_k,m_k,4}/[2(1-10/27x)];$$

$$I_{j_k,m_k,4}=\frac{3}{64}\frac{35m_k^4-5m_k^2[6j_k(j_k+1)-5]+3j_k(j_k^2-1)(j_k+2)}{j_k(j_k^2-1)(j_k+2)},\tag{5}$$

$$x=\frac{Z^2}{(4\pi/3)(R_0^3/e^2)10\tau}$$

where $\tau$ is the surface tension and $Z$ the "atomic number" of the core.

The total energy gain corresponding to the equilibrium values $\bar{\alpha}_2$, $\bar{\alpha}_4$ is:

$$\Delta E_{\text{tot}}=-\frac{\hbar^4}{16\pi R_0^6\tau M^2}\left\{\frac{5}{2}\left(\sum_{k=1}^{N+P}x_{n_k,l_k}^2I_{j_k,m_k,2}\right)^2\Big/(1-x)+\left(\sum_{k=1}^{N+P}x_{n_k,l_k}^2I_{j_k,m_k,4}\right)^2\Big/(1-10x/27)\right\}.\tag{6}$$

The sums in (5) and (6) include all states occupied by extranucleons. These states are to be filled in accordance with the exclusion principle; furthermore, for the ground state of nuclei this filling must be made in such a way that the unperturbed energy of the extranucleons plus the energy gain [Eq. (6)] should be a minimum.

It might be observed that when the extranucleons are grouped in saturated orbits the energy gain (6) vanishes and spherical symmetry is restored. This is consistent with the initial assumption of a core formed by nucleons clustered in saturated orbits.

For medium weight nuclei and for a single extranucleon, $\bar{\alpha}_4$ may be of the order of one-tenth of $\bar{\alpha}_2$, giving thus a very small contribution to the total energy gain (6).

An interesting consequence of the asymmetry of the model is the partial removal of $m$ degeneracy, so that the sublevels belonging to the same $l$ and $j$ are filled with pairs of protons (neutrons) with antiparallel total angular momenta. This reproduces one of the fundamental features of the $j$-$j$ coupling shell model with no need of a special hypothesis.

As for spin and magnetic moments, the present model leads to a coupling of A. Bohr's $B_2$-type.[3] In even-odd nuclei the spin would thus be equal or smaller than the odd nucleon total angular momentum $j$, and, in the case of a single extranucleon, the magnetic moments would fall on the $B_2$ curves of Bohr's paper.

A paper on these subjects is in press and will appear in the *Nuovo Cimento*.


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## The Beta-Spectrum of La[141]*


ROBERT B. DUFFIELD, *University of Illinois, Urbana, Illinois*

AND

LAWRENCE M. LANGER, *Indiana University, Bloomington, Indiana*


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THE beta-spectrum of $La^{141}$ has been investigated using a lens spectrometer. This 3.7-hour activity was discovered by Joliot-Curie and Savitch[1] but was not recognized as an isotope of lanthanum until the experiments of Hahn and Strassmann.[2] From an aluminum absorption curve on the radiation, Katcoff[3] reported the beta end point to be 2.8 Mev and concluded that there was little or no gamma-radiation.

The $La^{141}$ used in these experiments was made by slow neutron fission of uranium. One gram of $U^{235}$ was irradiated for 30 minutes in the thermal column of the Los Alamos fast reactor. The 18-minute $Ba^{141}$ was isolated and purified by precipitation as barium chloride. In the early experiments some difficulty was caused by small amounts of strontium activities carried along with the barium, so for the spectrometer samples the barium was reprecipitated ten times to get the necessary purity. The $Ba^{141}$ so isolated was allowed to decay for 60 minutes, and the $La^{141}$ which had grown in was precipitated as lanthanum hydroxide. This material was then mounted on a dural foil of thickness 0.7 mg/cm² to form the spectrometer sources. The active material had a thickness of 50 micrograms/cm², and autoradiographs showed the activity to be uniformly spread to within a factor of two over the entire area of the sources.

The Fermi plot of the data obtained is shown in Fig. 1. There is a high energy group with an end point at 2.43±0.03 Mev and a lower energy group with an end point at approximately 0.91 Mev. The relative intensity of the lower energy group is only about 5 percent. Its intensity remained unchanged during additional purification of the material so it appears unlikely that it was caused

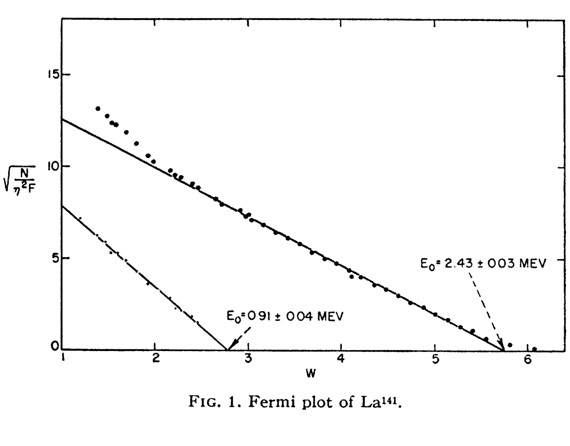


FIG. 1. Fermi plot of $La^{141}$.

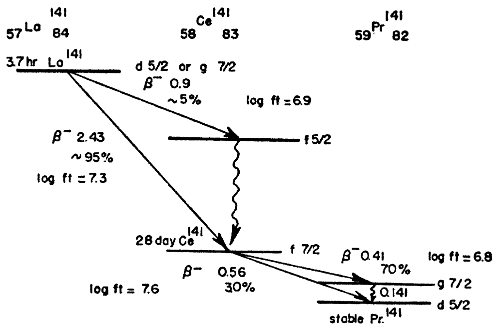


FIG. 2. Decay scheme of $La^{141}$.

by an impurity. The gamma-radiation from the source was examined with a sodium iodide crystal scintillation counter and pulse height selector. There appeared to be a gamma-ray of low intensity which decayed with a 3.7-hour half-life at approximately 1.3 to 1.6 Mev, but accurate measurements were not possible in the presence of the numerous gamma-rays from the small amounts of $La^{140}$ and $La^{142}$ unavoidably present in the sample. Beta-gamma coincidences, subject to the same difficulties, were observed at a rate which compared to $Sc^{46}$, was consistent with a beta-branch of 5 percent in $La^{141}$. The only coincidences observed were with betas of energy less than 1.5 Mev.

After the decay of the $La^{141}$, the gamma-rays from the $Ce^{141}$ formed in one of the spectrometer sources were examined with the scintillation counter. The 0.14-Mev gamma-ray was found, but no others were observed between 0.3 and 0.6 Mev.[4] If present, such gamma-rays could not have had intensities greater than 0.5 percent of that of the 0.14-Mev gamma-ray. Prompt beta-gamma coincidences were found, indicating that the 0.14-Mev gamma-ray follows a beta-branch.

These data are consistent with the decay scheme shown in Fig. 2. The levels shown for $Ce^{141}$ are taken from the summary of previous work in the National Bureau of Standards Circular 499. The spin of the stable $Pr^{141}$ has been experimentally determined[5] and the other spins have been chosen to agree with the beta-decay data and the nuclear shell model of M. G. Mayer.[6]

We are indebted to many members of the Los Alamos Laboratory for help with these experiments, particularly to Dr. B. E. Watt and Dr. B. C. Diven.

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## A Further Study of the Natural Activity of Lanthanum

R. W. PRINGLE, S. STANDIL, H. W. TAYLOR, AND G. FRYER
*Physics Department, University of Manitoba, Winnipeg, Canada*
(Received October 18, 1951)

IN an earlier communication[1] it was announced that an activity due to the naturally occurring $La^{138}$ isotope had been found in a search which was prompted by the isobaric relation of $La^{138}$ to the nuclei $Ba^{138}$ and $Ce^{138}$. In this investigation a scintillation spectrometer of low resolution was used to test the possibility of a gamma-radiation associated with such an activity, and it was estimated that ordinary lanthanum gave rise to 0.7 quanta/sec-g

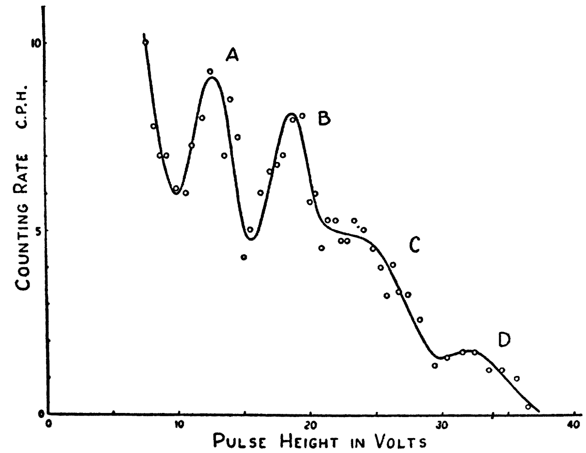


FIG. 1. Scintillation spectrometer pulse height distribution for the gamma-radiation of lanthanum, obtained with a five-channel kicksorter.

of energy 1.05 Mev although it was recognized that softer components might also be present. No search was made for the x-radiation which would be associated with a $K$ capture process, but the absence of electrons or positrons suggested that the gamma-ray was to be associated with a $K$ capture process to $Ba^{138}$.

A further study of this activity has recently been made with a scintillation spectrometer of improved resolution to determine whether the initial activity could have been due to some unsuspected short-lived contaminant, and also to investigate the possible complexity of the gamma-ray spectrum. The same highly purified 39 g $La_2O_3$ source was used, and surrounded a $\frac{3}{4}$-inch cube NaI-Tl crystal mounted on an E.M.I. 5311 photomultiplier. The spectrometer was enclosed in a 3-in. lead castle. The resulting pulse height distribution (Fig. 1), obtained with a Harwell Type 1074A five-channel kicksorter, gives three lines $A$, $B$, and $D$, attributed to gamma-rays of energy 535±15 kev, 807±15 kev, and 1390±30 kev in terms of the known gamma-radiation of $I^{131}$ and $Co^{60}$, used for calibration. The feature at $C$ corresponds to the 1390-kev gamma-ray Compton edge at approximately 1100 kev, and in the earlier low resolution experiment[1] had appeared to give the gamma-

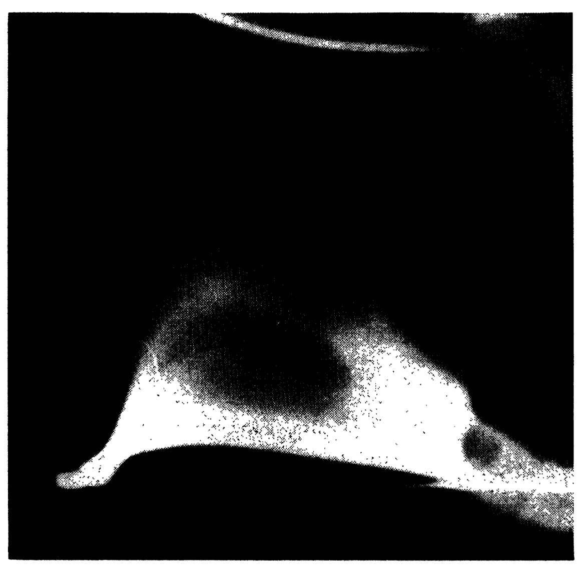

FIG. 2. Oscillogram of the scintillation spectrometer pulse height distribution for the gamma-radiation of lanthanum.