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Photoproton and Photoneutron Relative Yields

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MARQUEZ[1] has suggested a model for photonuclear reactions for the lighter elements in which the gamma-ray is absorbed by a single nucleon in a process similar to the photoelectric effect. There are many indications[1] that neither a statistical model in which nucleons evaporate from a compound nucleus nor a resonance model can fully explain photonuclear reactions in the light elements. If there is single particle interaction, as in the model of Marquez, one would expect the ratio $\sigma_{(\gamma,p)}/\sigma_{(\gamma,p)}$ to equal unity for different isotopes of the same light elements. This may be expected to be a more stringent test than the requirement that the ratio $\sigma_{(\gamma,p)}/\sigma_{(\gamma,n)}\cong 1$.

The betatron spectrum of 0- to 48-Mev gamma-rays were used to induce (γ,n) and (γ,p) reactions in magnesium and silicon. In order to measure (γ,p) to (γ,n) yield ratios in two different sets of magnesium isotopes a bar of spectroscopically pure magnesium metal was mounted directly in the beam and counted in place immediately after the beam was turned off. Changing the energy of the beam from 35 to 48 Mev or changing the shape and size of the sample produced no effect greater than the intrinsic errors of the experiment. This produced no effect greater than the intrinsic errors of the experiment. This was to have been expected since Perlman and Friedlander[2] have shown that relative yields are not affected by changing the beam maximum energy from 50 to 100 Mev. In all cases the relative yields reported here were determined by measuring the activity of the product nuclei. Two-particle reactions such as (γ,d), (γ,pn), and $(\gamma,2n)$ which produce the product nuclei have been neglected in computing relative yields. The results of the (γ,p) to (γ,n) yield ratios for two different sets of magnesium isotopes and the (γ,p) to (γ,p) yield ratio for a single set of magnesium isotopes are given in Table I.

In the case of elemental silicon the great difference of positron and electron energies in the (γ,n) and (γ,p) products makes an accurate yield ratio of (γ,p) to (γ,n) impossible with the set up used to determine this yield ratio in magnesium. However, it was possible using the traditional set up of bombarding and removing a thin sample to a shielded counter to obtain a yield ratio of (γ,p) to (γ,p) for silicon. The silicon used had no spectroscopic observable impurities greater than 0.003 of a percent and was bombarded in the form of a fine powder. Mountings were such as to reduce backscattering and absorption to a minimum. Except for the (γ,n) yield on magnesium in which the size of the sample was specifically studied, all yields were corrected for absorption using the curves of Perlman and Friedlander.[2]

TABLE I. Ratios of yields of (γ,n) and (γ,p) reactions.[a]

Parent isotope	Reaction	Product half-life	Product betas and energy (Mev)	Ratio of yields (this research)	Ratio of yields (Perlman and Friedlander)[b]
Si^{29}	(γ,p)	2.30 min	3.01	1.12±0.16	...
Si^{30}	(γ,p)	6.56 min	2.5 (70 percent) 1.4 (30 percent)	2.67±0.31	2.87
C^{12}	(γ,n)	20.35 min	0.970		
Mg^{25}	(γ,p)	14.9 hr	1.390	1.82±0.25	...
Mg^{26}	(γ,p)	62.5 sec	3.7 (55 percent) 2.7 (45 percent)	3.6 ±0.5	...
Mg^{24}	(γ,n)	11.9 sec	2.82		

[a] Note that the yield is given in between the columns of the parent isotopes and reactions which determine the yields. Thus the value 1.12, in between the Si^{29} and Si^{30} columns refers to the (γ,p) yield on $Si^{29}/(\gamma,p)$ yield on Si^{30}.
[b] See reference 2.

The (γ,p) irradiations on silicon were monitored by measuring the C^{11} activity induced in a weighed amount of spectrographically pure powered graphite. The monitors presented to the beam the same area cross section as did the targets and were always mounted in tandem. Only a single radioactive species was observed in the monitor over a period of six half-lives.

The relative yields of (γ,p) to (γ,p) for two silicon isotopes are shown in Table I. With the use of the monitor it is possible to compare the (γ,p) on Si^{30} to that obtained by Perlman and Friedlander.[2] The agreement is shown in Table I and is within experimental error.

Although it is not easily possible to make quantitative calculations because of the complexity of the betatron gamma-ray spectrum, it is immediately apparent that these are further data not easy to reconcile with the idea of evaporation from a compound nucleus. The energetics of proton or neutron emission in a compound nucleus determine the competition between the (γ,n) and the (γ,p) cross section. If the probability of creating the compound nucleus is assumed to be approximately the same for different isotopes of the same element, then from the energetics one would expect in general the Γ_p/Γ_n to be very different for different isotopes of the same element. Specifically, one expects for any model involving a compound nucleus the (γ,p) to (γ,p) yield ratios to be very different from one for the different isotopes of both Mg and Si. In the case of silicon the ratio $\sigma_{(\gamma,p)}/\sigma_{(\gamma,p)}$ equals unity within the experimental error for the isotopes Si^{29} and Si^{30}. In the case of magnesium the ratio is 1.82±0.25 for the isotope ratio Mg^{25}/Mg^{26}. This relatively high yield of Na^{24} may have arisen from its production by the process $Mg^{26}(\gamma,pn)Na^{24}$. It would appear from these limited data that there is a considerable contribution to photonuclear reactions for light elements of the type proposed by Marquez.[1]

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An Asymmetric Nuclear Model

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WE want to discuss here some features of an asymmetric nuclear shell model proposed by Rainwater.[1] This model may be fitted to predict nuclear quadrupole moments of the right order of magnitude.

We consider a core formed by the nucleons grouped in saturated orbits; this core is treated as a liquid drop whose surface acts on the remaining nucleons (which we shall call extranucleons) as an impenetrable barrier. It is also assumed that there is a strong spin-orbit coupling of the type:

$$\text{const.}\ \mathbf{l}\cdot\mathbf{s}. \tag{1}$$

The shape of the core may be described by:

$$R(\mu)=R_0[1+\Sigma_n \alpha_n P_n(\mu)], \tag{2}$$

R_0 being the radius of the undistorted core.

If deviations from the spherical shape are small, a perturbation method already described[2] may be applied to the calculation of

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:

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

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 $E_{n,l,j,m}$:

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

where $x_{n,l}$ is the nth 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 α'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:

$$\bar{\alpha}_2=\frac{\hbar^2}{4\pi R_0^4\tau M}\sum_{k=1}^{N+P}x_{n_k,l_k}^2 I_{j_k,m_k,2}/[4(1-x)/5];$$
$$I_{j_k,m_k,2}=j_k(j_k+1)-3m_k^2/4j_k(j_k+1),$$
$$\bar{\alpha}_4=\frac{\hbar^2}{4\pi R_0^4\tau M}\sum_{k=1}^{N+P}x_{n_k,l_k}^2 I_{j_k,m_k,4}/[2(1-10/27x)];$$
$$I_{j_k,m_k,4}=\frac{3}{64}\frac{35m_k^4-5m_k^2[6j_k(j_k+1)-5]+3j_k(j_k^2-1)(j_k+2)}{j_k(j_k^2-1)(j_k+2)}, \quad (5)$$
$$x=\frac{Z^2}{(4\pi/3)(R_0^3/e^2)10\tau}$$

where τ 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:

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

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}*

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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/cm^2 to form the spectrometer sources. The active material had a thickness of 50 micrograms/cm^2, 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

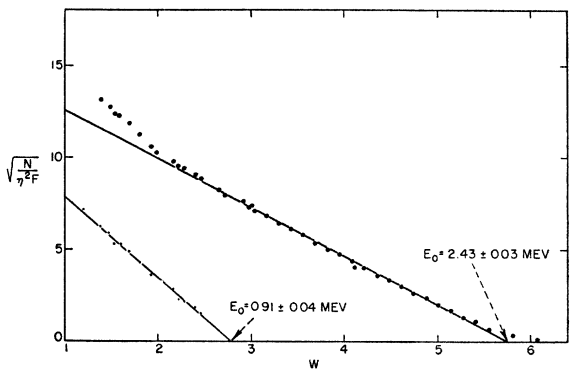

FIG. 1. Fermi plot of La^{141}.