This surely makes the identification easy (or possible), but it is not the only reason why such states are found in this region. In the intermediate region, the lowest odd-parity states could not appear so low; for example, in Mg^{24} one can exclude 3^-, 4^-, and 5^- states up to about 8 Mev, since the 9.4-Mev 4^+ ($T=1$) state does not decay into such states (no evidence of three or more gamma rays in cascade).

(4) In the heavy-element region, the effects of cores are very pronounced (around Pb, around $N=82$, and around $N=50$).

(5) Surprisingly enough, the points in light nuclei fall fairly well on the line, suggesting that these states are probably of shell-model nature like those in heavier nuclei. This is in agreement with the shell-model picture of the lower odd-parity states in O^{16}.[7]

The general trend shows the similarity of the lowest odd-parity states in even-even nuclei to the ground-state configurations of odd-odd nuclei in their symmetry character, namely, the existence of two unpaired nucleons (which interact rather weakly with each other).

This rule seems to be quite useful for the investigation of decay schemes. So far there seems to be no definite violation. There are some decay schemes where much lower lying odd-parity states have been considered. These seem to need further investigation.

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Radioactive Isotopes Cl^{40} and Ga^{74}†

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In order to look for more odd-parity states in even-even nuclei,[1] two previously unknown isotopes Cl^{40} and Ga^{74} were made and investigated. The ground states of these nuclei are most likely negative-parity states according to the shell model, and therefore allowed transitions to some of the negative-parity states would compete well with the transitions to lower even-parity states even though such odd-parity states have a relatively high energy. Moreover, the forbiddenness of the high-energy beta component can keep the half-life of these isotopes fairly long in spite of the high decay energy which is expected from beta energy systematics.

In order to produce Cl^{40}, solid argon was bombarded by fast neutrons from a beryllium target bombarded by 10-Mev deuterons from the Purdue cyclotron. Gamma-ray measurements made after the neutron irradiation showed gamma rays with energies of 1.46 Mev, 2.75 Mev, and 6.0 Mev, in addition to the 1.37-Mev gamma ray attributed to the 110-min A^{41} produced by the (n,γ) reaction on A^{40} and the 3.1-Mev radiation due to S^{37} produced by the (n,α) reaction on A^{40}. From both gamma-ray measurements with a NaI scintillator and beta-ray measurements with a GM counter, the half-life of this new activity was found to be about 1.4 min. Since Cl^{40} is the only unknown isotope which could be produced by irradiating argon and since moreover the energy of one of the gamma rays (1.46 Mev) coincides with the energy of the first excited state of A^{40},[2] this new activity is attributed to Cl^{40}. Also, the assignment of this activity to chlorine is confirmed by chemical separation.

The beta spectrum of this activity was investigated with the aid of a 2×2×2 in. Plastifluor scintillator and was found to extend up to about 7.5 Mev. There is also at least one strong lower energy component which has its end point between 3.0 and 3.5 Mev. The intensity of the 2.75-Mev gamma ray is found to be close to that of the 1.46-Mev gamma ray by comparison of the spectrum with that of Na^{24} taken by the same spectrometer. These characteristics suggest a decay scheme as given in Fig. 1(b). The decay energy is in good agreement with the beta energy systematics.

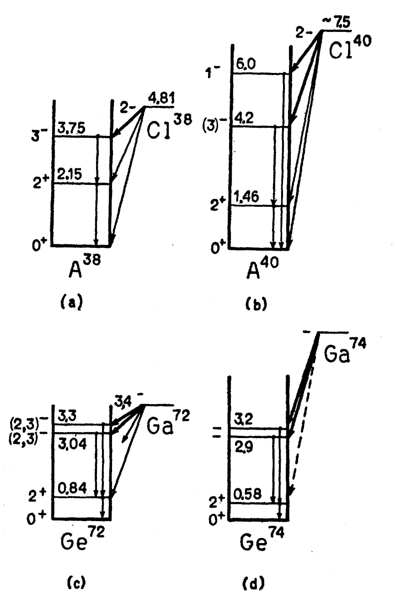

Fig. 1. Proposed decay schemes of Cl^{40} and Ga^{74} compared with known decay schemes of Cl^{38} [Kraushaar, Mihelich, and Sunyar, Phys. Rev. **95**, 456 (1954)] and Ga^{72} [Kraushaar, Brun, and Meyerhof, Phys. Rev. **101**, 139 (1956)]. In the decay scheme of Ga^{72} (c), only the major components of the beta and gamma radiations are shown. For the fit with the systematics of odd-parity states, see the figure in reference 1.

The second excited state seen here is most likely to be an odd-parity state because of the low comparative half-life of the beta transition to this state, and spin 3 is preferred to 2 on account of the Glaubman and Talmi rule. The energy value is just about what is expected.[1]

Ga^{74} was produced by bombarding pure germanium metal with the same neutron source. Very many gamma rays with various half-lives were observed after the bombardment, but all could be assigned to some known isotopes produced by fast neutrons on Ge, except for three distinct gamma rays with energies 0.58, 2.3, and 2.6 Mev which decayed with a half-life of about 8 min. All the possible activities expected from neutron irradiation of Ge are known except those of Ga^{74} and Ga^{76}, and the yield of the latter is expected to be much smaller than that of the former because of the high (n,p) threshold and the more unfavorable isotopic content. Also, the energy of one of the gamma rays agrees well with that of the first excited state of Ge^{74}.[2] Therefore this activity is assigned to Ga^{74}.

It is rather difficult to determine the decay scheme from this, but it is noticed that the gamma-ray intensity distribution looks quite similar to that of Ga^{72}, just as the Cl^{40} decay is similar to the decay of Cl^{38}. Also, from the systematics of odd-parity states, odd-parity states can be expected at around 3 Mev. Therefore, the decay scheme of Ga^{74} is probably like that given in Fig. 1(d).

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Bremsstrahlung in High-Energy Nucleon-Nucleon Collisions

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PREVIOUS studies of the bremsstrahlung emitted in high-energy nucleon-nucleon collisions have treated the interaction between the two particles in the Born approximation[1]; this procedure is certainly incorrect for the high-energy gamma rays, where the spectrum shape is modified by the strong interaction in the low-energy final state of the two nucleons. In this note we show that the spectrum, for gamma-ray energies sufficiently close to the end point that the final nucleons are in an S state, can be calculated by a method similar to that used in calculating the spectrum of π mesons produced in nucleon-nucleon collisions.[2] This calculation predicts a peak in the bremsstrahlung spectrum for high-energy gamma rays, a measurement of which would provide interesting information about nucleon-nucleon interactions.

Consider first the neutron-proton bremsstrahlung, with the final state being a ^3S state. As a special case, the final state may be a deuteron, giving a discrete line 2.2 Mev above the end point ω_0 of the continuous spectrum; the cross section for deuteron formation is determined from the principle of detailed balancing to be

$$d\sigma_0=3\omega_0(2M)^{-1}d\sigma_d(\omega_0),$$

where M is the mass of a nucleon, and $d\sigma_d$ is the photodisintegration cross section. The energy is supposed to be nonrelativistic but much greater than the deuteron binding energy B. In general, we may write

$$M_{fi}=-(2\omega)^{-\frac{1}{2}}(\psi_f,J\psi_i),\quad J=\int \mathbf{j}(\mathbf{x})\cdot\boldsymbol{\varepsilon}e^{-i\mathbf{k}\cdot\mathbf{x}}d^3x. \quad (1)$$

Let $J=J_0+J'$, where J_0 is the contribution of the ordinary current associated with free particles, and the remainder J' represents effects such as meson exchange; furthermore, let $H=H_0+H'$, where H' gives the interaction between the two particles, and let ϕ denote an unperturbed state. Then

$$\begin{aligned}(2\omega)^{\frac{1}{2}}M_{fi}\\ &=-(\psi_f,J'\psi_i)-(\psi_f,J_0\phi_i)\\ &\qquad+(\psi_f,J_0[H_0-E_i-i\epsilon]^{-1}H'\psi_i)\\ &=-(\psi_f,J'\psi_i)\\ &\quad+\textstyle\sum_n(\psi_f,H'\phi_n)(E_n-E_f-i\epsilon)^{-1}(\phi_n,J_0\phi_i)\\ &\quad+\textstyle\sum_n(\psi_f,J_0\phi_n)(E_n-E_i-i\epsilon)^{-1}(\phi_n,H'\psi_i).\end{aligned}\quad (2)$$

The contribution of the first two terms depends only on $\psi_f(x)$ for points x within the range R of nuclear forces, and this is also true of the less important third term for sufficiently high-energy gamma rays. While $\psi_f(x)$

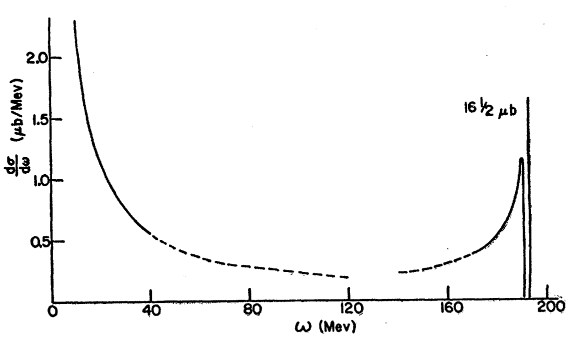

Fig. 1. Predicted bremsstrahlung spectrum (in the c.m. system) for collisions of 400-Mev neutrons with protons. The discrete line with a 16½-μb cross section corresponds to deuteron formation. The low-energy curve is the semiclassical result, which is known to be correct in the limit; the high-energy peak is predicted by the calculation in the text.