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Validity of the Pauli exclusion principle for nucleons

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The validity of the Pauli exclusion principle for nucleons has been investigated. The mean life against p-shell nucleons in ^{12}C falling into the fully occupied $1s_{1/2}$ shell has been shown to be $> 6 \times 10^{27}$ sec (99.7% confidence limit). A limit has also been obtained for the relative amplitude of symmetric components in the wave functions of nucleons.

[RADIOACTIVITY ^{12}C, measured $T_{1/2}$ against violation of Pauli exclusion principle; NaI(Tl) detector.]

The Pauli exclusion principle is of fundamental importance and its considerable success in explaining a wide range of phenomena indicates that it can be applied with a very high degree of validity. The limits of the validity, if indeed there are any, have not been tested extensively by direct experimental investigation. In atomic physics the validity of the principle for electrons has been investigated by Reines and Sobel[1] but no direct investigations seem to have been made for nucleons.

We have investigated the validity of the exclusion principle for nucleons. A preliminary account of this work has been given.[2] If the exclusion principle is violated then nucleons inside nuclei can fall into lower energy levels, levels which are normally regarded as being fully occupied. The possibility of nucleons in the p shell of ^{12}C falling into the fully occupied $1s_{1/2}$ shell has been investigated by searching carefully for the γ rays which would be emitted during the transition. The positions of the s and p shells of ^{12}C are reasonably well established from such reactions as $(p,2p)$ (Refs. 3, 4) and γ rays with energies centered on ~20 MeV are expected to be emitted in a violation process.

A 213 g graphite cylinder, 3 cm high and 7.3 cm in diameter, was placed to be coaxial with a 10.2 × 12.7 cm diameter NaI(Tl) detector with its face 1 cm from the detector face. Over a period of about three months numerous runs were made, each run lasting about one day. Background was estimated by removing the graphite cylinder. Spectra were accumulated in an MCA for the photon energy range of $0 \rightarrow 35$ MeV. At lower photon energies the dominant background radiations were the 1.46 MeV γ rays from ^{40}K and the 2.61 MeV γ rays from ^{208}Tl. At higher energies the background showed no peaks due to monoenergetic γ rays and was associated with cosmic rays. Considerable care was taken to stabilize the gain of the detector electronics and frequent checks were made with γ rays ranging in energy up to 4.43 MeV.

The mean life τ against a p-shell nucleon violating the exclusion principle was estimated from

$$N_\gamma = \frac{N_p \epsilon}{\tau}.$$

N_γ is the difference in the counting rate between the graphite cylinder being in position and then being removed. These γ rays are assumed to be due to $p \rightarrow s$ shell ^{12}C nuclear transitions and the analysis was for the range of $5 - 32.6$ MeV, which is above the energies of the observed γ rays from radioactive impurities.

N_p is the number of p-shell nucleons in the sample. A ^{12}C nucleus contains 8 nucleons in the p shell and N_p was estimated to be 8.43×10^{25}.

ϵ is the efficiency of the NaI(Tl) detector. This was estimated from calculated efficiencies and from considerations of the γ-ray energy which would be emitted by the ^{12}C nucleus. Unfortunately experimental efficiency data are scarce at higher energies and we also have the complication of a large volume source. Theoretical predictions of the efficiency are available for point sources placed at distances ranging from 1 to 4 cm from a 10.2 × 12.7 cm diameter NaI(Tl) detector.[5] We assumed 20 MeV γ rays were being emitted from point sources at distances of 1, 2, 3, and 4 cm from the face of the detector, which scans across the position occupied by the graphite cylinder. For the last three positions an allowance was made for attenuation in the carbon and, with this absorption allowance included, the mean value of the detector efficiency for the four positions was calculated to be 0.17. This value is only approximate, being based on theoretical predictions without any consideration of the details of the γ-ray energy spectrum, and the radial distribution of the source has been ignored. In order to be conservative in deriving a limit for τ we have taken ϵ as 0.15. A more refined estimate of ϵ would allow a more accurate limit to be placed on τ but would not change our general conclusions.

N_γ was measured to be (-0.0016 ± 0.0007) γ/sec. The uncertainty is a statistical standard deviation. In any one measurement of N_γ the uncertainty due to possible gain drifts was $<30\%$ of the statistical uncertainty and, after many separate measurements, it was assumed this could be neglected. The result for N_γ is consistent with a null result. Our interpretation is to regard the counting rate of γ rays associated with violation of the exclusion principle as being less than three standard deviations of the uncertainty in the value of N_γ. Then at 99.7% confidence level N_γ is $< 2.1 \times 10^{-3}$ γ/sec and this gives a limit of $\tau > 6 \times 10^{27}$ sec. This result is in strong support of the very high validity of the exclusion principle.

Any violation of the exclusion principle could be due to the wave function ψ for nucleons having a small symmetric component. A similar approach was used by Reines and Sobel in analyzing their result for electrons in atoms.

We can write $\psi = \psi_a + \alpha\psi_s$ where ψ_a and ψ_s are antisymmetric and symmetric wave functions. The value of α can be estimated by comparing τ with the lifetime for a conventional transition in which a 20 MeV γ ray would result from a transition to a hole in the $1s_{1/2}$ shell of ^{12}C. The lifetime for a conventional transition in ^{12}C would be $\sim 10^{-18}$ sec. A comparison of the two lifetimes gives a limit of $\alpha < 1.3 \times 10^{-22}$.

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