DETERMINATION OF THE ROOT-MEAN-SQUARE RADIUS OF THE CHARGE DISTRIBUTION IN THE He^3 NUCLEUS FROM PHOTONUCLEAR EFFECT EXPERIMENTS*

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The measurement of the root-mean-square radius of the charge distribution in the lightest nuclei, and in particular in H^3 and He^3 nuclei, is of great interest, since it serves as a good criterion for the correctness of the wave functions chosen for the ground state of these nuclei.

The root-mean-square radius $<R_c^2>^{1/2}$ of the charge distribution can be determined from scattering experiments with high-energy electrons [1]. Another possible method of determining $<R_c^2>^{1/2}$ are experiments in which the the total effective cross section σ_{E1} for electric dipole absorption of photons by the nucleus is measured.

It was shown by Levinger and Bethe [2] on the basis of Siegert's theorem that the integral cross section $(\sigma_{-1})_{E1}$, for electric dipole absorption of photons by a nucleus, weighted over the bremsstrahlung radiation spectrum, is given by the expression

$$(\sigma_{-1})_{E1}=\int_0^\infty \sigma_{E1}(W)\,\frac{dW}{W}=\frac{4\pi^2}{3}\left(\frac{1}{hc}\right)\langle \mathbf{D}^2\rangle_{00}, \quad (1)$$

where $\mathbf{D}=(ZN/A)e\mathbf{R}_{pn}$ is the electric dipole moment of the nucleus with respect to its center of mass; $\mathbf{R}_{pn}=\mathbf{R}_p-\mathbf{R}_n$, $\mathbf{R}_p$ is the radius vector of the center of mass of the protons in the nucleus; $\mathbf{R}_n$ is the radius vector of the center of mass of the neutrons. Foldy [3] showed that if the wave function of the ground state of the nucleus is completely symmetric with respect to the spatial coordinates of all the nucleons, then

$$\langle R_{pn}^2\rangle=\frac{A^2}{ZN(A-1)}\langle R^2\rangle,$$

where $<R^2>^{1/2}$ is the root-mean-square radius of the charge distribution in the nucleus (for point nucleons). Consequently,

$$(\sigma_{-1})_{E1}=\frac{4\pi^2}{3}\left(\frac{e^2}{hc}\right)\frac{NZ}{A-1}\langle R^2\rangle. \quad (2)$$

It should be noted that his expression was obtained without any assumptions regarding the nuclear forces and the wave functions, except their spatial symmetry.

Thus, by measuring σ_{-1} for electric dipole absorption, the quantity $<R^2>^{1/2}$ can be calculated.

For the determination of the experimental value of $(\sigma_{-1})_{E1}$ for the He^3 nucleus, the effective cross sections of the two possible photonuclear reactions on He^3 were measured, i.e., $He^3(\gamma,p)D^2$ and $He^3(\gamma,n)2p$ for $E\gamma_{max}=$ $=170$ MeV by means of a cloud chamber in a magnetic field filled with He^3. On the basis of these data we calculated the integrals

$$(\sigma_{-1})_{\gamma,p}=\int_0^{170}\sigma_{\gamma,p}(W)\frac{dW}{W}=(1.34\pm0.05)\text{ mbarn}$$

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and

$$(\sigma_{-1})_{\gamma,n}=\int_0^{170}\sigma_{\gamma,n}(W)\frac{dW}{W}=(1.42\pm0.07)\,\text{mbarn}$$

(only the statistical errors are given). The experimental value is thus $\sigma_{-1}=(2.76\pm0.08)$ mbarn.

Analysis of the experimental angular distribution of the protons emitted in the reaction γ, p showed that the contribution of electric quadrupole absorption to $(\sigma_{-1})_{\gamma,p}$ amounts to $(8.5\pm2)\%$. If we assume the same contribution of $E2$ absorption to $(\sigma_{-1})_{\gamma,n}$, then

$$(\sigma_{-1})_{E1}=(2.53\pm0.12)\ \text{mbarn}$$

Hence, by using formula (2) we find for the root-mean-square radius of the charge distribution in the He^3 nucleus in the case of point nucleons: $\langle R^2\rangle^{1/2}=(1.62\pm0.06)$ fermi or, if the finite radius of the proton charge distribution is taken into account,

$$\langle R_p^2\rangle^{1/2}=(0.805\pm0.011)\ \text{fermi} \qquad (3)$$

and for the relation

$$\langle R_c^2\rangle=\langle R^2\rangle+\langle R_p^2\rangle,$$

we obtain

$$\langle R_c^2\rangle^{1/2}=(1.81\pm0.06)\ \text{fermi}$$

The latter value is in satisfactory agreement with the value $\langle R_c^2\rangle^{1/2}_{He^3}=(1.97\pm0.1)$ fermi obtained recently in the experiment of Hofstadter's group with the scattering of high-energy electrons on the He^3 nucleus [5]. It should be noted, however, that the value of $\langle R_c^2\rangle^{1/2}$ obtained in our experiments of the photonuclear effect on He^3 is somewhat smaller than the value obtained in $e-He^3$ scattering experiments. This discrepancy may be an additional indication of the incomplete symmetry of the wave function of He^3. As was shown by Schiff [6], the difference observed in Hofstadter's experiments between the form factors of the charges of the H^3 and He^3 nuclei (or between the root-mean-square radii of these nuclei) may be due to a small admixture of a state with mixed symmetry (S'-state) to the completely symmetric S-state.

Davey and Valk [7] calculated $(\sigma_{-1})_{E1}$ with the gaussian wave functions (containing 3.5% of the S'-state) used by Schiff [6] for describing $e-He^3$ and $e-He^3$-scattering results. They found that a 3.5% admixture of the S'-state reduces $(\sigma_{-1})_{E1}$ by 8.5%. It was also shown that in this case the formula for $(\sigma_{-1})_{E1}$ for H^3 and He^3 nuclei can be represented in the form

$$(\sigma_{-1})_{He^3}=(\sigma_{-1})_{H^3}=\frac{4\pi^2}{3}\left(\frac{e^2}{\hbar c}\right)\langle R^2\rangle_{H^3}. \qquad (4)$$

If the state S' is missing, this formula agrees with that of Foldy since then $\langle R^2\rangle_{H^3}=\langle R^2\rangle_{He^3}$. If there is an admixture of the S'-state, then, by using formula (3) and the measured value of $(\sigma_{-1})_{E1}$ for the He^3 nucleus, we actually determine the charge distribution radius for the H^3 nucleus, and not for the He^3 nucleus. Hence it follows that the value $\langle R_c^2\rangle^{1/2}=(1.81\pm0.06)$ fermi found above should be compared with the value $\langle R_c^2\rangle^{1/2}_{H^3}=(1.68\pm0.17)$ fermi measured in the $e-H^3$-scattering experiments of the Hofstadter group. The satisfactory agreement between these values shows that the assumption of a S'-state admixture in the ground state of three-particle nuclei does not contradict the available experimental data.

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