CONCERNING THE α-PARTICLE ABSORPTION MECHANISM OF STOPPED PIONS BY ^{16}O NUCLEI

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Experimental data on the absorption of stopped π^- mesons by various nuclei were obtained in [1,2]. In particular, measurements were made of the shape of the Doppler line of γ radiation of the ^{12}C nucleus in the state 2^+ with excitation energy 4.44 MeV, produced when a pion is captured by a ^{16}O nucleus. The authors of these papers reached the conclusion that the considered state of the ^{12}C nucleus is produced as the result of direct single-step interaction of the pion with the ^{16}O nucleus.

In [1], the measured shape of the Doppler line is compared with the theoretical one calculated under the assumption that the pion is absorbed by an α cluster in the 1d state in the field of a harmonic oscillator characterized by a parameter $Q=\sqrt{\frac{1}{2}\mu\hbar\omega}$, where μ is the reduced mass of the α particle and of the ^{12}C nucleus, and ħω is the oscillator quantum. In addition, it was assumed that the capture of the pion is exclusively from the 1s state of the mesic atom. By regarding Q as a fitting parameter, a value Q = 77 ± 5 MeV/c was obtained for it. At the same time, the experimental data on the scattering of electrons by nuclei [3] yield for ^{16}O a value Q = 139 MeV/c.

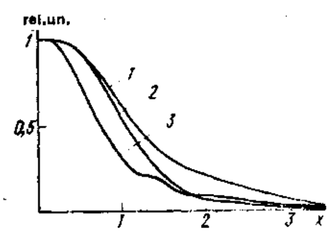

Fig. 1. Shape of Doppler line for various values of the cutoff radius: 1 — $R_0=0$, 2 — $R_0=2$ Ф, 3 — $R_0=5$ Ф.

To eliminate this contradiction, we calculated the shape of the Doppler line for the considered case, without using many of the simplifying assumptions employed in [1]. Let us list the distinguishing features of our approach.

1. As the wave function that describes the relative motion of the α cluster and of the nucleus $^{12}C(2^+)$ in the initial nucleus $^{16}O(0^+)$ we used the function of the oscillator 2d state, and not the 1d state, as was done in [1]. The choice of the wave function corresponds to the fact that in this case there are four oscillator quanta for the relative motion.

2. It was shown in [4-7] that besides capture from the 1s state of the mesic atom of oxygen, a substantial contribution is made by capture of pions from the 2p state. In our calculation we used the following values of the partial widths and absorption strengths:

$$\Gamma_{1s}^{abs} = 7{,}56\ \text{keV}, \quad \Gamma_{2p}^{abs} = 4{,}7\ \text{eV}, \quad \omega_s = 8{,}5\%, \quad \omega_p = 91{,}5\%.$$

3. In [1] they neglected the interaction of the particles with the nucleus in the initial and final states. In our calculation this interaction was taken into account within the framework of the plane-wave method with cutoff [8,9], i.e., it was assumed that in the reaction take part not only those α clusters of the target nucleus which are outside a sphere whose radius R_0 is chosen to satisfy the condition that the widths at half-height of the theoretical and experimental Doppler line be equal. The oscillator potential parameter had in this case a fixed value Q = 139 MeV/c.

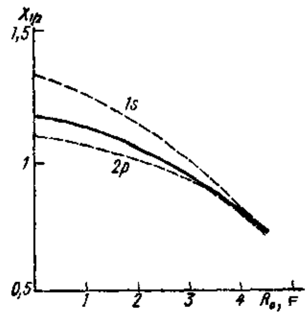

Fig. 2

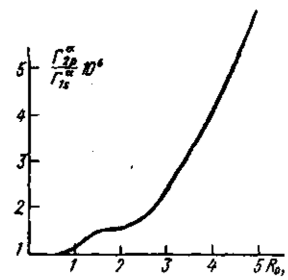

Fig. 3

Fig. 2. Dependence of the half-width of the Doppler line on the cutoff radius.

Fig. 3. Dependence of the ratio of the partial capture widths in the α-particle channel from the 2p and 1s states of the mesic atom on the cutoff radius.

4. It is known that the oscillator wave functions describe poorly the motion of the clusters in the surface layer of the nucleus. Therefore, following [8], we used as the asymptotic function the spherical Hankel function. The point of matching the asymptotic with the oscillator function was determined from the condition of continuity of the logarithmic derivative.

The results of the calculations are shown in Figs. 1-3. In Fig. 1 it is shown how the form of the Doppler line changes with changing radius R_0 of the cutoff of the radial integral. The abscissas represent the quantity

$$x = \frac{Mc}{\sqrt{2}\,Q}\,\frac{E - E_0}{E_0},$$

where E is the energy of the γ quantum, E_0 = 4.44 MeV is the energy of the γ transition, M is the mass of the ^{12}C nucleus. Figure 2 shows a plot of the half-width $x_{1/2}$ of the Doppler line at half-height as a function of R_0. The dashed curve is the same plot in the case when the pion is captured only from the 1s or only from the 2p states of the mesic atom. Figure 3 shows the ratio $\Gamma^{\alpha}_{2p}/\Gamma^{\alpha}_{1s}$ of the partial capture widths in the α-particle channel from the 2p and 1s states as a function of the cutoff radius R_0. The ratio of the yields of the reaction of capture from these states is

$$\delta = \left(\omega_p \frac{\Gamma^{\alpha}_{2p}}{\Gamma^{abs}_{2p}}\right) \Big/ \left(\omega_s \frac{\Gamma^{\alpha}_{1s}}{\Gamma^{abs}_{1s}}\right).$$

At R_0 we get δ = 1.7. With increasing R_0, the relative contribution of the capture from the 2p state increases and, for example, at R_0 = 3.5 F it reaches δ = 4.7.

According to [2], the experimental value of the width of the Doppler line at half-height is $2\varepsilon_{1/2} = 137$ keV. It corresponds to $x_{1/2} = 0.875$. With the aid of Fig. 2 we find that R_0 = = 3.65 F. It is of interest to compare this value of the cutoff radius with the value R_0 = 3.78 F obtained in [8] in an analysis of the reaction $^{16}O(\alpha, 2\alpha)^{12}C(0^+)$ at E_α = 26 MeV within the framework of the mechanism of quasi-elastic knockout of the α particles.

Thus, an analysis of the absorption of stopped pions by the ^{16}O nucleus within the framework of the α particle capture mechanism makes it possible to obtain the experimental value of the width of the Doppler line, emitted from the state 2^+ (4.44 MeV) of the ^{12}C nucleus. The values of the parameters Q and R_0, which characterize the motion of the α cluster in the ^{16}O nucleus, agree with the values obtained in an investigation of some other reactions with this nucleus. It must be noted, however, that to draw final conclusions it is necessary to have calculations with more correct allowance for the interaction of the particles with the nucleus in the initial and final states.

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REFERENCES

1. C. W. Lewis, H. Ullrich, H. D. Engelhardt, and E. T. Boschitz, Phys. Lett., vol. 47B, p. 339, 1973.
2. H. D. Engelhardt, C. W. Lewis, and H. Ullrich, Nucl. Phys., vol. A258, p. 480, 1976.
3. L. R. Elton, Nuclear Sizes, Osford U. Press, 1961.
4. W. W. Sapp, M. Eckhauser Jr., G. H. Miller, and R. E. Welsh, Phys. Rev., vol. C5, p. 690, 1972.
5. G. Backenstoss and S. Charalambus, Phys. Lett., vol. 25B, p. 365, 1967.
6. G. Poelz and H. Schmitt, Phys. Lett., vol. 26B, p. 331, 1968.
7. J. D. Vergados, Phys. Rev., vol. C12, p. 1278, 1975.
8. V. V. Balashov and D. V. Meboniya, Nucl. Phys., vol. A107, p. 369, 1968.
9. Y. Sakamoto, P. Cuer, and F. Takeutchi, Phys. Rev., vol. C11, p. 668, 1975.

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