Pion charge-exchange reaction and transition densities to isobaric analog states

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Distorted wave impulse approximation calculations were performed for the (π^+,π^0) reaction to isobaric analog resonances in a series of nuclei employing two types of transition densities. The calculations are sensitive to the types of transition densities used, giving substantially different cross sections in the two cases.

[NUCLEAR STRUCTURE Pion charge exchange to isobaric analog states.]

Two types of transition densities are often used for the isobaric analog states (IAS). One form of the transition density involves only the densities of excess neutrons:

$$\rho_{\rm exc}(r)=\sum_i |\phi_i(r)|^2 , \tag{1}$$

where $\phi_i(r)$ are the wave functions of the excess neutrons computed in the parent system. A different prescription is to compute the difference between the total neutron density and the total proton density, thus

$$\rho_n(r)-\rho_p(r)=\sum_\nu |\phi_\nu(r)|^2-\sum_\pi |\phi_\pi(r)|^2 , \tag{2}$$

where ϕ_ν and ϕ_π are the wave functions of the neutron and proton occupied orbits, respectively. The difference between the two densities in Eqs. (2) and (1),

$$\delta\rho(r)=[\rho_n(r)-\rho_p(r)]-\rho_{\rm exc}(r) , \tag{3}$$

is due to the Coulomb polarization of the nucleus.[1] This quantity was extensively studied in the past and is well understood.[1] The two densities differ appreciably in the inside region. In a recent paper[2] it was pointed out that the two forms of densities have quite different values also at the surface, and beyond the surface region in those nuclei in which the number of protons is large and the number of excess neutrons is small. Good examples were[2] ^{41}Ca, ^{42}Ca, and ^{58}Ni. It was noted[2] that in reactions of strongly absorbed particles which take place on the surface the use of one or another form for the transition density will give quite different cross sections for these reactions. This is especially true for the pion charge exchange reaction.[3–6] In fact, using a geometrical model[6] which depends only on the value of the transition density at some effective radius $\bar{R}$ just outside the nucleus, one finds[2] large differences in the (π^+,π^0) cross sections when one uses either Eq. (1) or (2) for the transition density to the IAS. In ^{41}Ca the ratio was about 21 and in ^{42}Ca 3 in favor of the transition density $\rho_{\rm exc}$. In the above paper[2] it was also argued that Eq. (1) should be used for the transition density to IAS, and thus the larger cross sections are the correct ones.

In the present work we explore the (π^+,π^0) reaction to IAS in the framework of the DWIA theory[3–5] for a series of nuclei, focusing our studies on the problem of transition densities to IAS.

The transition densities in Eqs. (1) and (2) were obtained from a Hartree-Fock (HF) calculation with a Skyrme III force.[7] The parent nuclei we considered were ^{41}Ca, ^{42}Ca, ^{44}Ca, ^{46}Ca, ^{48}Ca, ^{90}Zr, and ^{208}Pb. In the case of the open shell Ca isotopes we assumed a spherical shape for the ground state (g.s.). The transition densities $\rho_{\rm tr}=\rho_{\rm exc}$ and $\rho_{\rm tr}=\rho_n-\rho_p$ for the Ca isotopes were shown in Ref. 2. In Fig. 1 we show the two types of densities for ^{90}Zr and ^{208}Pb. The difference between $\rho_{\rm exc}$ and $\rho_n-\rho_p$ are not as large as, for example, in ^{41}Ca but they are still substantial. We should emphasize here that the density difference $\rho_n-\rho_p$ in such large excess neutron nuclei as ^{208}Pb contains some unphysical contributions due to the spurious isospin mixing introduced by the HF approximation in the case of

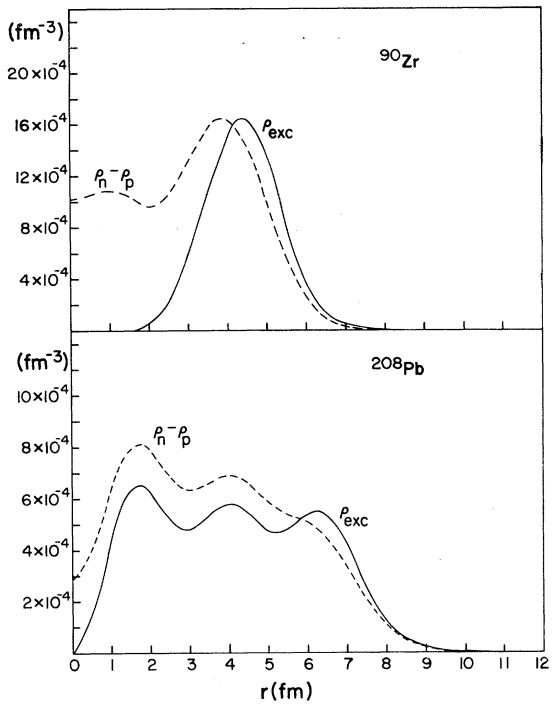

FIG. 1. The Hartree-Fock ρ_{exc} and $\rho_n-\rho_p$ densities in ^{90}Zr and ^{208}Pb.

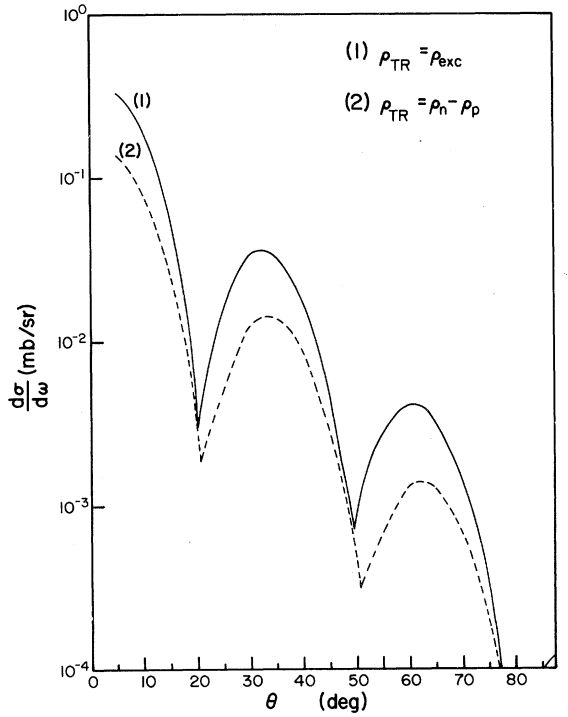

FIG. 2. The calculated (π^+,π^0) differential cross section in ^{42}Ca computed for the two different transition densities ρ_{exc} and $\rho_n-\rho_p$, using the Kisslinger optical potential.

TABLE I. The calculated (π^+,π^0) integrated and forward angle differential cross sections. In the first line for each of the nuclei are given the integrated cross sections (in μb) and in the second line the differential cross sections for $\theta=5°$ (in μb/sr). The results are presented for two different optical potentials, the Kisslinger and local (Laplacian) ones.

Optical potential	Kisslinger model		Local (Lapacian)	
ρ_{tr}	ρ_{exc}	$\rho_n-\rho_p$	ρ_{exc}	$\rho_n-\rho_p$
^{41}Ca	41.0	7.8	46.8	9.4
	168.7	17.4	171.5	21.8
^{42}Ca	80.4	34.7	91.2	38.7
	330.5	138.5	334.2	141.8
^{44}Ca	156.5	98.8	176.7	108.5
	645.2	422.6	651.4	423.8
^{46}Ca	219.9	156.0	247.3	170.2
	910.6	676.8	917.5	674.4
^{48}Ca	309.9	232.1	345.1	250.1
	1275.0	999.6	1267.0	979.5
^{90}Zr	108.3	58.1	129.5	66.4
	465.1	252.9	500.0	269.2
^{208}Pb	132.7	96.2	161.4	112.4
	659.2	496.6	701.2	517.3

$N-Z\neq 0$, but in nuclei with a small neutron excess such as ^{41}Ca, ^{42}Ca these impurities are small.

The DWIA calculations for the (π^+,π^0) reaction were performed with a computer code obtained from the (π,π') pion inelastic scattering code[8] we adapted to the case of single charge exchange and to the case when the transition densities are microscopic ones. The (π^+,π^0) calculations were performed for two types of pion-nucleus potentials[1–5]; the Kisslinger potential and the Laplacian (local) potential and pion energy of $E_\pi=180$ MeV. In Table I the (π^+,π^0) forward direction $(\theta=5°)$ differential cross sections (in μb/sr) and the angle-integrated cross sections (in μb) for the IAS transition are given for each nucleus. It is clear from the above results that the cross section is strongly dependent on the type of transition density used. In Fig. 2 the (π^+,π^0) angular distributions in ^{42}Ca for the two transition densities and for the Kisslinger potential are shown. We see that even the shapes of these distributions are somewhat different for the two densities. The $\rho_n-\rho_p$ transition density at radii beyond the surface is smaller than ρ_{exc}. The Coulomb polarization contribution of the core $\delta\rho$ is negative outside the nucleus because the Coulomb force slightly expels the protons with respect to the

core neutrons.[1] The effect on the (π^+,π^0) cross section is very large for the nuclei ^{41}Ca and ^{42}Ca because there are only a few excess neutrons and the weight of the Coulomb core polarization contribution in $\rho_n - \rho_p$ is significant in this case. These results hold for both the Kisslinger and Laplacian potentials, and there is very good agreement in the forward and integrated cross sections for the two optical potentials.

The ratio of the forward angle cross sections evaluated with ρ_{exp} and $\rho_n - \rho_p$ is almost 10 in ^{41}Ca and comes down to 1.3 in ^{48}Ca. In ^{90}Zr this ratio is 1:8 and in ^{208}Pb 1:3. Thus the present calculation confirms the estimates given in Ref. 2. It was suggested in the above reference that the correct way to calculate the charge-exchange process to the IAS is by taking ρ_{exc} as the transition density, which means that the larger cross sections are the more appropriate ones. Recently the forward pion charge-exchange cross sections were measured[9] in the Los Alamos π^0 spectrometer for pion energies of $E_\pi = 180$ MeV. The preliminary experimental results[9] for the even Ca isotopes are such that in ^{42}Ca the forward angle cross section is about a factor of 2 larger than the one we computed; however, in ^{48}Ca the measured integrated cross section and the one calculated *with* ρ_{exc} are in agreement.

Although the reaction mechanism of the pion charge-exchange reaction is not yet fully explored and understood,[3-6] it is encouraging to find that the reaction is sensitive to some properties of the density and may in the future add information about nuclear structure.

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